FINAL REPORT

Characterization of Releases to Surface Water from the Rocky Flats Plant

Task 2: Verification and Analysis of Source Terms

August 1999

Submitted to the Colorado Department of Public Health and Environment, Disease Control and Environmental Epidemiology Division, Rocky Flats Health Studies in partial fulfillment of Contract No. 100APPRCODE 391

"Setting the standard in environmental health"

RAC

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EXECUTIVE SUMMARY

The Rocky Flats Environmental Technology Site is owned by the U.S. Department of Energy (DOE) and is currently contractor-operated by Kaiser-Hill Company. For most of its history, the site was called the Rocky Flats Plant (RFP) and was operated by Dow Chemical Company as a nuclear weapons research, development, and production complex. The RFP is located about 8–10 km from the cities of Arvada, Westminster, and Broomfield, Colorado and 26 km (16 mi). northwest of downtown Denver, Colorado.

Through a 1989 Agreement in Principle between the DOE and the State of Colorado, DOE provided the State with funding and technical support for health-related studies. The purpose of the Historical Public Exposures Studies on Rocky Flats was to identify potential health effects in residents in nearby communities who may have been exposed to past toxic and radioactive releases.

Phase I of the study was performed by ChemRisk (a division of McLaren/Hart, Environmental Engineering). In Phase I, ChemRisk conducted an extensive investigation of past operations and releases from the RFP. *Radiological Assessments Corporation* (*RAC*) was awarded the contract to conduct Phase II of the study, an in-depth investigation of the potential doses and risks to the public from historical releases from Rocky Flats. During Phase I ChemRisk did not develop radionuclide and chemical source term estimates for surface water releases because they could not locate continuous effluent monitoring data for all release points from the site. Instead, they evaluated water monitoring data for radioactivity in drinking water supplies from reservoirs downstream of the Rocky Flats Plant for their potential impact on offsite populations. In Phase II, the Health Advisory Panel recommended that additional characterization of the treatment and release of liquid effluents from the site.

This report documents the evaluation of the liquid effluent procedures and facilities at the Rocky Flats Plant and focuses on the early years of operations (before 1975). The methods used onsite to collect, transport and treat liquid wastes before they were discharged offsite are described. Contaminants in the plant's wastewater were released from Rocky Flats into the creeks on the Site. Even in the early 1950s, however, when the plant was built, well-defined liquid waste handling procedures were used to reduce the amount of plutonium released offsite. A special building was constructed in 1952 to process plutonium liquid wastes. All liquid wastes, containing fairly high levels of plutonium, coming directly from the plutonium processing areas were sent directly to the waste processing facility for removal of the plutonium. In the very early years, the treated wastewater was then discharged directly into the creeks. An onsite sewage treatment plant handled the site's normal liquid wastes. A more complex sewage treatment system was built in December 1974.

There were two series of ponds constructed at the site for two different purposes. The holding ponds, a series of uncovered and unlined ponds, were constructed on Woman Creek and on the north and south branches of Walnut Creek. The holding ponds provided an important measure in decreasing the levels of radioactivity in water that was released off the site. The first three holding ponds were built in the early 1950s. Eight additional ponds were added over the years. After allowing the solid material in the wastewater to settle to the bottom and after testing the water, plant officials gradually released the pond water into the creeks flowing eastward off the plant site.

The second series of ponds, called the solar evaporation ponds, were built onsite in the mid-1950s. These ponds, which served a different purpose than the holding ponds, were built in response to concern about high releases of nitrates when homes were first built in an area of Broomfield. These ponds were constructed to hold and allow the evaporation of liquids that had low levels of radioactivity but high concentrations of nitrates.

At times, these systems did not operate as effectively as they should have. Sometimes liquid wastes with some plutonium contamination drained directly into the creeks. In the 1950s, some modifications were made to reduce the amount of plutonium liquid wastes discharged directly to the creeks. However, periodic releases of untreated wastes continued until 1965 because of equipment problems and leakage.

Liquid waste from the asphalt-lined solar evaporation ponds was never intended to be released into the creeks. However, leakage sometimes occurred through cracks in the lining. Due to problems with leakage, the solar evaporation ponds were often relined with upgraded materials to prevent further releases from occurring. However, leakage from the ponds was detected at various times beginning in the 1950s. The five solar ponds have not been used to hold industrial process water since 1986. By 1996, the sludge had been removed from all the solar ponds.

The largest concentrations of plutonium flowed from Rocky Flats to the creeks during two time periods: in the early 1950s before the holding ponds were built, and from 1972–1973, when the holding ponds were drained and reconstructed. At that time, some of the pond water and sediments flowed downstream to Great Western Reservoir, a drinking water source for the City of Broomfield. In the past, the highest levels of plutonium were detected in water that went into the South Walnut Creek from the B series holding ponds. Much of the plutonium in liquid wastes settled to the bottom of the holding ponds and eventually in the sediments at the bottom of Great Western Reservoir. Levels of radioactivity in water from Walnut Creek at Indiana Street (the plant's eastern boundary) increased almost 80 times during the peak rebuilding phase. By June 1973, the radioactivity levels had returned to pre-pond reconstruction levels.

The report briefly reviews the analysis of waste water for uranium, after 1971 when uranium-specific measurements were made. After that time, the highest measured annual concentrations of uranium were measured in the A ponds (2–11 pCi L^{-1}) and B ponds (1–7 pCi L^{-1}) on Walnut Creek, which drained into the GWR. The C ponds on Woman Creek, which drained into Standley Lake, had the lowest concentrations of uranium during this period (0.5–5 pCi L^{-1}).

Tritium was released accidentally from the plant on several occasions when tritium-contaminated scrap plutonium was processed. The greatest amounts were released to surface water in April 1973, when wastewater containing tritium flowed into Walnut Creek leading to Great Western Reservoir. The highest tritium concentrations measured in the reservoir during this time were about two to 20 times higher than normal.

Overall, the risk to the public was small from releases of contaminants from Rocky Flats into surface water. Analysis of releases of contaminants to surface water shows that the 1973 tritium release was the major contributor to risk for the surface water pathway. Following the tritium release in 1973, urine samples were taken from 36 people who lived or worked in Broomfield, and drank water from the reservoir. The average tritium concentration for these people was about seven times higher than normal (4,300 picocuries per liter versus 600 picocuries per liter). Three years after the release, urine samples were again taken from the same group; results indicated that their tritium concentrations were back to normal.

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INTRODUCTION

The Rocky Flats Environmental Technology Site is owned by the U.S. Department of Energy (DOE) and is currently contractor-operated by Kaiser-Hill Company. For most of its history, the site was called the Rocky Flats Plant (RFP) and was operated by Dow Chemical Company as a nuclear weapons research, development, and production complex (Figure 1). The RFP is located on approximately 2,650 ha (6,500 acres) of Federal property, about 8–10 km from the cities of Arvada, Westminster, and Broomfield, Colorado and 26 km (16 mi) northwest of downtown Denver, Colorado. The original 156 ha (385 acre) main production area is surrounded by a 2,490-ha (6,150-acre) buffer zone that now delineates the RFP boundary.

Through a 1989 Agreement in Principle between DOE and the State of Colorado, DOE provided the State with funding and technical support for health-related studies. The purpose of the Historical Public Exposures Studies on Rocky Flats is to identify potential health effects in residents in nearby communities who may have been exposed to past toxic and radioactive releases. The Colorado Department of Public Health and Environment (CDPHE) first invited a national panel of experts to help design the health studies. Because of intense public concern about Rocky Flats contamination among Denver metropolitan area residents following a Federal Bureau of Investigation raid of Rocky Flats in June 1989, the panel decided to stress public involvement and to separate the research into two major phases conducted by two different contractors to enhance accountability and credibility.

Phase I of the study was performed by ChemRisk (a division of McLaren/Hart, Environmental Engineering). In Phase I, ChemRisk conducted an extensive investigation of past operations and releases from the RFP. The Phase I effort identified the primary materials of concern, release points and events, quantities released, transport pathways, and preliminary estimates of dose and risk to offsite individuals. The conclusions from Phase I were released in a public summary document (HAP 1993), a series of task reports by ChemRisk, and several articles in the journal *Health Physics*.

Radiological Assessments Corporation (*RAC*) was awarded the contract to conduct Phase II of the study, which is an in-depth investigation of the potential doses and risks to the public from historical releases from Rocky Flats. Recommendations for work to be performed in Phase II are outlined in the Phase I summary document HAP (1993).

After reviewing the ChemRisk reports from Phase I of the current Rocky Flats Historical Public Exposure Studies, *Radiological Assessments Corporation* (*RAC*) and the Health Advisory Panel (HAP) for the project supported the finding that releases of radionuclides and chemicals to surface water from the Rocky Flats Plant (RFP) be more fully characterized (Grogan et al. 1994). ChemRisk did not develop radionuclide and chemical source term estimates for surface water releases because they could not locate continuous effluent monitoring data for all release points from the site. Instead, they evaluated water monitoring data for radioactivity in drinking water supplies from reservoirs downstream of the Rocky Flats Plant (RFP) for their potential impact on offsite populations (ChemRisk 1994). Conservative screening calculations were used to calculate radiation doses associated with the elevation of radioactivity measured in the Great Western Reservoir (GWR), which has been linked to Rocky Flats releases. Their results suggested that contamination of the primary reservoirs (GWR and Standley Lake) from Rocky Flats releases was possible but inconclusive.

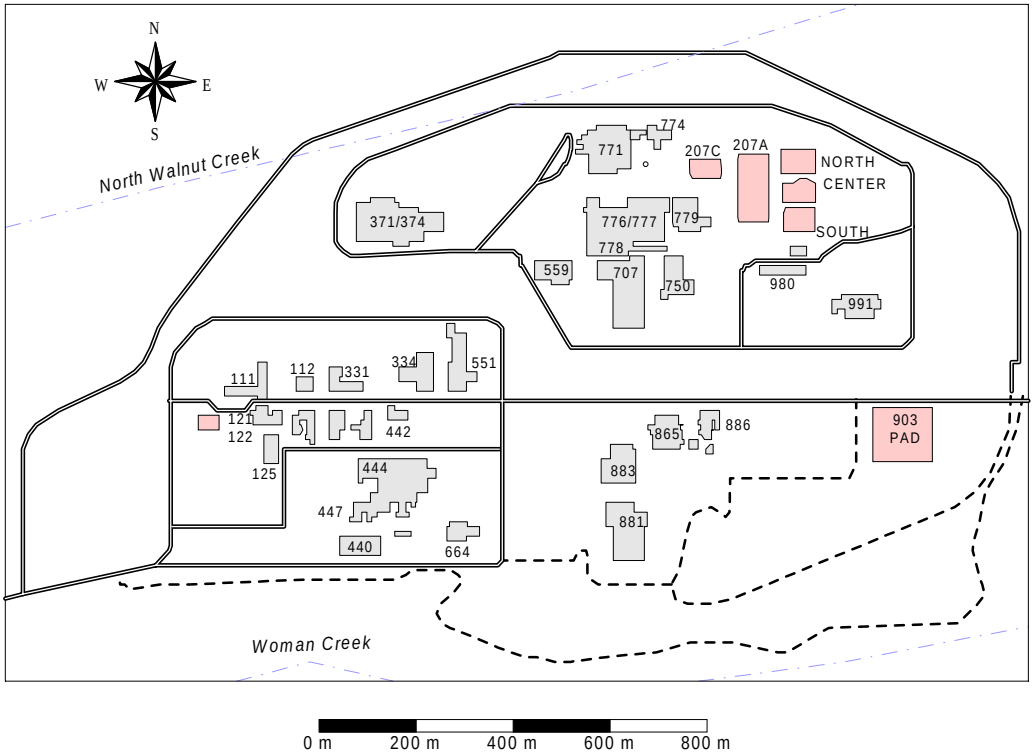

Figure 1. Main production area of the Rocky Flats Plant. Originally, the buildings were identified with two-digit numbers. Later, a third digit was added. The production area, now sometimes called the industrial area, is surrounded by a security perimeter fence. The area between the perimeter fence and Indiana Street to the east is the buffer zone. The buffer zone was expanded to Indiana Street in the 1970s. Woman Creek runs to the south and North Walnut Creek runs to the north of the site.

As part of the follow-up to Phase I work, the HAP recommended that "the identification of additional environmental data that could be used to establish whether the predicted exposures from the surface water pathway are consistent with actual measurements taken in the environment" be given high priority as part of the Phase II. This recommendation required some knowledge of the methods used onsite to collect, transport and treat liquid wastes before they were discharged offsite. It also implies that further review of the offsite water monitoring data be done. The characterization of releases to surface water from the RFP and the evaluation of surface water monitoring data fall within Tasks 2 and 4 of the Phase II work:

- Task 2. Verification of the radionuclide and chemical release estimates and associated uncertainties that were developed during Phase I of the project.
- Task 4. Evaluation of historical environmental data, which can provide a basis for risk assessment and for reconstruction of releases.

Based on the review of the Phase I work, *RAC* concluded that additional study of surface water transport at the site was needed to determine the historical significance of the data. It was clear from Phase I that releases of radionuclides and chemicals in surface water could be more fully described if additional documentation could be found.

First, *RAC* focused on how liquid wastes were processed and handled at the site. Subsequently, the routine surface water monitoring data from the site and from the Colorado Department of Public Health and Environment (CDPHE) that ChemRisk evaluated in Phase I, were reviewed. This latter work is summarized in the *RAC* Task 4 report, *Evaluation of Historical Environmental Data* (Rope et al. 1999).

In Phase I, ChemRisk evaluated past offsite water monitoring data to determine potential exposures associated with surface water releases instead of developing traditional radionuclide and chemical source term estimates for surface water releases.

Of the materials of concern identified in Phase I, only gross alpha activity, and later, plutonium, were measured regularly in liquid effluents leaving the site. No routine air or liquid effluent monitoring of carbon tetrachloride, a solvent used extensively at the RFP to clean and degrease equipment, or other chemicals was done at the RFP in the past. However, *RAC* did evaluate the potential impact of historic carbon tetrachloride releases to surface water (McGavran and Rood 1999). This current report describes how liquid wastes and effluents were handled at the RFP in the early years of operation, and outlines one approach to estimating past releases of plutonium in surface water from the RFP. The following section presents some of the key questions and answers about this report.

SUMMARY QUESTIONS OF MAIN POINTS

Why is RAC reviewing onsite liquid effluent handling and characterizing releases to surface water?

After reviewing the Phase I reports for the current project (Grogan et al. 1994), *RAC* recommended, and the Health Advisory Panel (HAP) agreed that releases of radionuclides and chemicals to surface water from the Rocky Flats Plant (RFP) needed to be more fully characterized. During Phase I, ChemRisk had not developed radionuclide and chemical source term estimates for surface water releases due to the lack of sufficient effluent data to develop estimates of release (ChemRisk 1994). Instead, they evaluated monitoring data for radioactivity in drinking water supplies from reservoirs downstream of the Rocky Flats. To more fully study this potential exposure pathway, *RAC* evaluated how liquid wastes and effluents to surface water were handled at the site, and searched for historic records which would help support release estimates for key materials discharged to the surface water.

What documentation sources can provide the type of information needed?

Both historic and recent records are useful in understanding how liquid effluents were handled onsite, and how and when environmental monitoring of surface waters were done. In addition to the relevant documents that ChemRisk located in Phase I, *RAC* located additional historical documents in the Environmental Master File at Rocky Flats, and at the Federal Records Center in Denver. These records included some original analytical data sheets for measurements of contaminants in liquid effluents for various years (Dow 1952–1953, 1960, 1961, 1969–1972). Current ongoing site characterization and remedial investigation activities at Rocky Flats provided supplementary documentation. In addition, there were extensive discussions with personnel at the Colorado Department of Health and at the Rocky Flats site regarding past releases.

What were the key liquid waste treatment facilities onsite in the early years?

There were several facilities at the site constructed specifically to handle liquid wastes.

Building 774 was built in 1952 to process plutonium liquid wastes from Building 771.

Building 374 was built in 1980 to meet the increasing demand for liquid waste handling.

Building 995 was the sewage treatment plant.

Building 442 and Building 556 were the laundry facilities.

Building 24 was the water treatment plant.

Holding ponds (A, B, C) were unlined, earthen ponds designed to hold wastes meeting drinking-water standards.

Solar evaporation ponds were initially asphalt lined and intended to hold chemically contaminated process wastes meeting the radioactive standards for onsite storage.

What time period is of interest for evaluating surface water releases from Rocky Flats?

The focus for the Historic Public Exposures Studies is on the effluent handling system prior to the mid 1970s, the time of interest for dose reconstruction. Several changes in processing liquid effluents were made onsite about that time. For example, liquid effluent from the sanitary sewer system was discharged directly to South Walnut Creek until 1974, and backwash from the water filtration system was discharged directly to Woman Creek until 1975. In 1972, a stream gauging station was established by the U.S. Geological Service on Walnut Creek. While water samples from the Rocky Flats Plant (RFP) had been collected and analyzed since 1951, before the operations began in 1952, the extent of the monitoring program, the spatial distribution of sampling and the types of materials measured were fairly limited until the early 1970s, when routine plutonium analysis was first done.

How useful is routine effluent monitoring conducted by RFP Contractors from 1952–1971?

The data can be useful for observing general trends in the levels of contaminants over time that may have resulted from Rocky Flats Plant operations. To accomplish this goal, it is important to know what contaminants (radioactive and chemical contaminants) were monitored, the frequency of sampling (routine program or special studies or project), the sampling locations, who collected and analyzed the samples, and the quality of the data.

What is the potential use of this information?

This information provides more understanding of how materials were handled onsite, and allows the estimation of liquid waste volumes and quantities of some materials released offsite. Furthermore, it provides some perspective for offsite environmental monitoring measurements that were made in surface streams, reservoirs, and in sediments. Environmental monitoring data can be used for spatial and temporal trends, and to provide information on the relative magnitude of routine releases.

DOCUMENTATION SOURCES

Both historic and recent records are useful in understanding how liquid effluents were handled onsite, and how and when environmental monitoring of surface waters were done. In addition to the relevant documents that ChemRisk located in Phase I, the most useful historic

documents were found in the Environmental Master File at Rocky Flats, and at the Federal Records Center in Denver, where some original analytical data sheets for measurements of contaminants in liquid effluents for various years (Dow 1952–1953, 1960, 1961, 1969–1972) were located. Current ongoing site characterization and remedial investigation activities at Rocky Flats have provided supplementary documentation. In addition, *RAC* had numerous contact and discussions with staff at the CDPHE and at RFP. The following list describes some of the key report series used in this analysis.

Original handwritten site survey and environmental logbooks. Logbooks for certain time periods in 1952, 1953, 1959, 1960, 1961, 1969-1970, 1971-1972, 1974, 1975, 1979 (Dow 1952–1953, 1960, 1961, 1969–1972) listed the location and type of sample, quantity, counts per minute, activity, lab initials of the analyst, count initials, background (blank counts), and remarks. There were usually written comments on the counting efficiency, and the use of spiked samples, as well. For early years, the efficiency factors and equations for water sample activity were based on Hanford procedures. Experiments relating to methods of analysis are documented.

Progress Report—Waste Disposal Unit. These monthly reports were authored by E. S. Ryan. The first monthly report, dated January 1953, introduced the newly organized Waste Disposal Unit, organized under the authority of John G. Epp at the direction of F. H. Langell. The purpose of the unit was "the supervision of the ultimate disposal of processed liquid and solid waste, and the correlation of the allied data." The reports contained summary descriptions of plant activities until September 1953, when the volume and alpha activity levels in the liquid wastes (treated, untreated, and laundry) released from the main processing areas were given. In July 1954, the name was changed to *Progress Report for the (month, year)—Waste Disposal Co-ordination Group.*

A series of monthly waste disposal reports from 1953 onward were very valuable in compiling information on liquid wastes. These reports provided a summary of the liquid wastes, treated and untreated, that were released from buildings to ponds and from ponds to offsite reservoirs.

Progress Report—Waste Disposal Co-ordination Group. Ryan was still the author of these monthly reports, which were published from July 1954 through December 1954. The reports included a summary of the liquid wastes released, listed the discharges from Building 71, the drums of contaminated waste in storage at RFP, and a breakdown of the shipments made during the month to Arco (Idaho Falls, Idaho) and the costs for offsite disposal at Arco. In January 1955, the report name was changed to *History Report—Process Waste Disposal Group*.

History Report—Process Waste Disposal Group. Ryan was still the author of these monthly reports. They provided a short description of work onsite, and summarized the liquid wastes, activity levels in the final holding ponds, the drums of contaminated waste in storage at various buildings onsite, and a breakdown of the trailer shipments to Arco (Idaho Falls). Some also listed the aqueous liquid wastes received, processed, and released from Building 74 to either the Solar Evaporation Ponds or to Walnut Creek. Information for these monthly reports came from handwritten log sheets at the Sanitary Treatment Plant and Building 74, the process waste

treatment plant. The name of the report was changed to *Status Report—Health Physics Waste Disposal* in January 1965.

Status Report—Health Physics Waste Disposal. The author was E.S. Ryan, and the reports summarized the quantity and activity levels in liquid wastes, treated and untreated, which were released from buildings to holding ponds, and from ponds to Walnut Creek and then to the GWR. After May 1971, this report name changed to *Waste Management Status Report—Waste Disposal*.

Waste Management Status Report—Waste Disposal. This report was similar to the *Status Report—Health Physics Waste Disposal* monthly reports and summarized the same type of information. In addition, it gave a breakdown of the number of trailers and railcars of waste shipped to Idaho Falls. In June of each year, there was a summary of liquid wastes, other than sanitary, released under the supervision of the process waste disposal group during the fiscal year. This summary indicated the type of waste (untreated or treated in Building 74), where the effluent originated, whether it was released to the holding ponds (series A and B) or to the onsite evaporation ponds, the number of discharges, the total volume, and total activity.

Environmental Survey Reports. Beginning in late 1959, quarterly reports were written "in compliance with Presidential Executive Order of August 14, 1959" to tabulate the daily average, maximum, and minimum values for continuous sampling of particulate alpha and beta activity in the air by month (Dow 1960). They usually listed the long-lived radioactivity of particulates in air, radioactivity in raw surface water from GWR, Standley Lake, Baseline and Ralston Reservoirs, and vegetation sample results from near the RFP and in surrounding communities. ChemRisk analyzed these data for Phase I. The reports included area maps showing sampling locations.

GENERAL SURFACE WATER FLOW

The general features of surface water flows around the Rocky Flats Plant have been well documented. The flow of water in the Rocky Flats area runs from west to east with the surface water supplying water to two reservoirs, the GWR and Standley Lake, which are used as municipal water sources and for recharging aquifers used for domestic water supply (Figure 2). The water that moves through the waterways results from direct surface runoff following periods of rainfall and snowmelt, flow supplied by seeps and springs, and wastewater from the RFP.

Five streams and five ditches drain the general environs of the RFP with many smaller tributaries that drain into these streams.

Streams	Ditches
• North Walnut	• Last Chance Ditch
• South Walnut	• Church Ditch
• Woman Creek	• McKay Ditch
• Coal Creek	• Kinnear Ditch and Reservoir Co. Ditch
• Rock Creek	• Smart Ditch

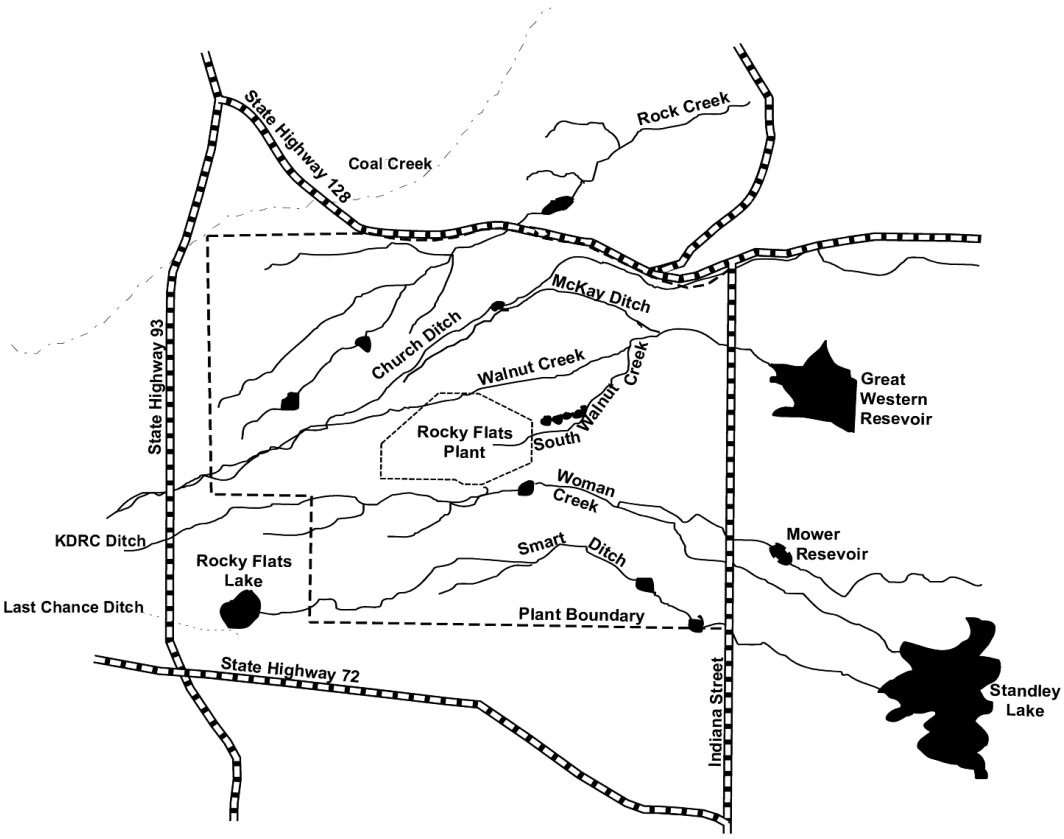

Figure 2. Location of key streams and reservoirs in the Rocky Flats area, adapted from EG&G (1991). North and South Walnut Creeks drain the RFP site and discharge into the Great Western Reservoir to the east. Woman Creek flows into Standley Lake. The KDRC (Kinnear Ditch & Reservoir Co. Ditch) transports water from Coal Creek to Woman Creek. Last Chance Ditch drains into Rocky Flats Lake, south of the RFP. The inner plant security fence marks the original boundary of the site. The “buffer zone” that was established in the 1970s is outlined with the dashed line marked "plant boundary", with Indiana Street as the eastern boundary.

Three of the major water streams, North Walnut, South Walnut, and Woman Creek, are particularly important because they drain the RFP site, which had numerous waste areas within and outside the early site boundary (cattle fence). Because these waste sites were used for storage, burial, incineration, and for spraying liquid effluents (spray fields), they were potential sources of runoff and leaching to the main streams (Figure 3). For example, leachate from the Landfill Pond, located directly north of the site, drained into North Walnut Creek and eventually to GWR (ChemRisk 1992). The frequency and amount of surface runoff depended upon factors such as soil infiltration capacity, surface vegetation, and slope. The clay loam soils have a relatively low infiltration capacity due to clay content, except where fractures may increase permeability. Rainfall gauges were installed on Woman Creek, Walnut Creek, and other Rocky

Flats stations in 1972. Rainfall intensities for a period in the early 1970s ranged from less than 0.1 inch (2.5 mm) per hour to about 0.5 inches (12.7 mm) per hour (Hurr 1976).

In the fall and early spring, frontal storms can occur in the area with long, low-intensity rainfall. In the late spring and summer months, short, intense cloudbursts produce greater surface runoff than the frontal storms (DOE 1991). Vegetation is sparse; the monitoring of that media is discussed in the Task 4 report (Rope et al. 1999).

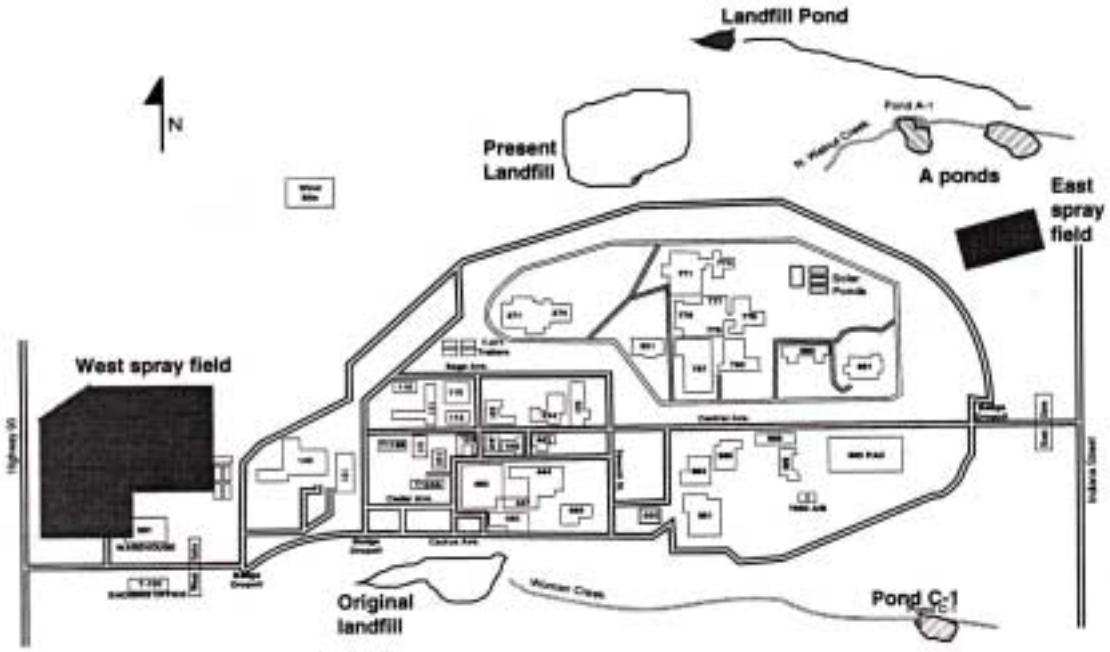

Figure 3. A diagram of the Rocky Flats Plant showing some of the waste storage and disposal facilities that were outside the original site boundary. The original landfill was used from 1952–1968 for various plant wastes, including some radioactive and chemical wastes. The present landfill has operated since 1968; up through February 1970, sanitary sewer sludge was buried there. The spray fields were used to spray water from the solar evaporation ponds (west field) and from Pond B-3 (east field). The west field was used from 1982–1985; the east field was used for a short time in 1989.

Hurr (1976) did one of the first comprehensive studies of the surface water and groundwater hydrology of the RFP area to determine how contaminants would be distributed spatially and temporally as they moved through the hydrological system. Walnut Creek drains into the GWR, while Woman Creek flows into Standley Lake, which is about 3.3 miles southeast of the RFP. Woman Creek drains about 35% of the Rocky Flats site, particularly the southeastern part.

Standley Lake was formed by an earthen dam constructed on Big Dry Creek in 1910 to supply water for irrigation. The full capacity of the lake is about 43,000 acre-ft, with an average depth of about 36 ft (11 m) (Clow and Johncox 1995). Beginning in 1965, Standley Lake also provided drinking water for the cities of Westminster, Thornton and Northglenn, which are located 4 mi (6.4 km) southeast, 8 mi (12.8 km) east, and 7 mi (11.2 km) northeast of Standley Lake (Werkema 1974, Thompson 1975). In 1996, the new Woman Creek Reservoir was completed to prevent Rocky Flats surface water from flowing directly into Standley Lake. Water

in the new reservoir is then pumped to Walnut Creek below the GWR, where it flows downstream into Big Dry Creek and the South Platte River.

The other major reservoir in the area is GWR, in northeastern Jefferson County about 1.5 mi (2.4 km) east of the RFP. GWR has an earthen dam that was built in 1904 and originally was designed to supply water for irrigation. The lake is owned and operated by the city of Broomfield, which is located 2 mi (3.2 km) northeast of GWR, and supplied drinking water to the city from 1955–1992. The full capacity of the lake is about 3250 acre-ft. Walnut Creek flowed from the RFP directly into the GWR until 1992 when the Walnut Creek water was diverted around GWR (DOE 1991, Clow and Johncox 1995).

Water samples have been collected from the Rocky Flats area and analyzed for radioactivity since 1951, before operations began. Surface water is one of three environmental media (air, vegetation, and surface water) that were monitored routinely throughout the 1950s and 1960s.

The Last Chance Ditch discharged water to Rocky Flats Lake and Twin Lakes. Smart Ditch transported water from Rocky Flats Lake to the east. Church and McKay Ditches supplied water to the GWR, and the KDRC Ditch supplied water by way of Woman Creek to Standley Lake.

STREAM FLOW ON CREEKS IN THE ROCKY FLATS AREA

The U.S. Geological Survey (USGS) established four stream-gauging stations on North Walnut, South Walnut, and Woman Creeks in 1972 to measure outflow from the plant area. Daily stream flow measurements were made at these locations (one each on Walnut and south Walnut Creeks and two on Woman Creek). The monthly stream flow data for three of the gauging stations are summarized in Tables A-1, A-2 and A-3 in Appendix A of this report. Figures 4a, 4b, and 4c show the average, maximum, and minimum monthly flow rates from mid1972 through 1974. The flow rate in all three streams showed some seasonal variation, especially in North Walnut Creek. Woman Creek had the highest median flow rate of approximately 0.4 cubic feet per second (cfs) (10,000 gal hr^{-1}) over this time period. The flow in Woman Creek ranged from no flow to a maximum of 60 cfs (1.5 million gal hr^{-1}) in May 1973 during an extensive period of rain. The median flow rate in North Walnut Creek was 0.3 cfs (7,500 gal hr^{-1}), while South Walnut Creek had a median flow of 0.2 cfs (~5,000 gal hr^{-1}), half of that measured in Woman Creek. These records also show that there were days with no natural stream flow particularly during late summer and early fall, which is typical for small streams in this region.

The USGS began measuring stream flow in North and South Walnut Creeks, and in Woman Creek in 1972. The average flow rate ranged from 5000–10,000 gallons (19,000–38,000 liters) per hour.

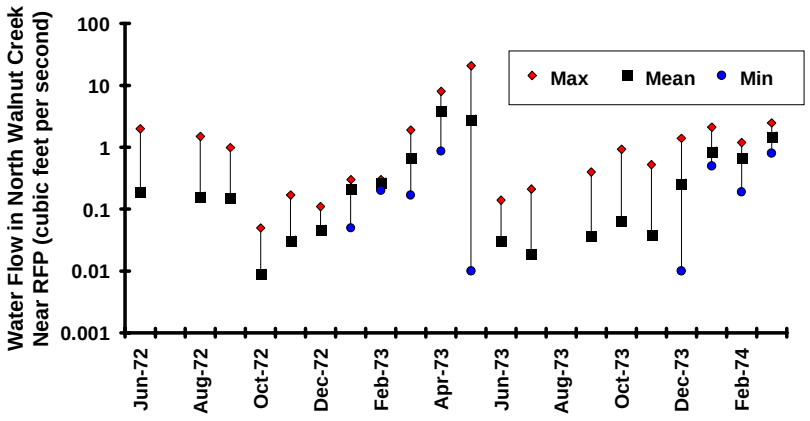

Figure 4a. North Walnut Creek

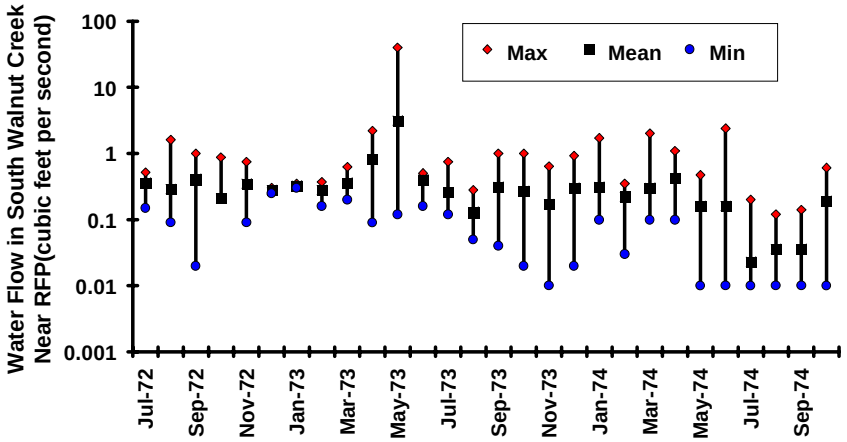

Figure 4b. South Walnut Creek

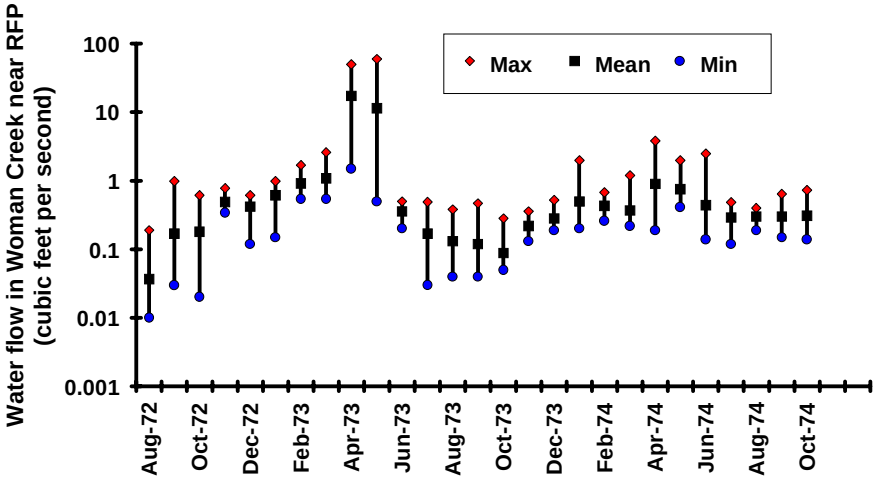

Figure 4c. Woman Creek

Figure 4. Stream flow measured by the U.S. Geological Survey (Hurr 1976) in North Walnut Creek 1 km east of RFP (4a), South Walnut Creek 1 km east of RFP (4b), and in Woman Creek just southeast of the site (4c).

Although no routine stream flow data were collected prior to 1972, there are indications that the data reasonably represent the stream flow characteristics for earlier years (Hurr 1976). For example, Johnson et al. (1974) noted that the type of plant growth in the area of the A- and C-series ponds indicated no major disturbance in the previous 5 to 10 years. Furthermore, current stream flow measurements support these earlier data (EG&G 1993b). Figure 5 compares the stream flow data from the early 1970s to the early 1990s, measured in South Walnut Creek before entering the holding ponds. The average flow for both periods was similar, about 0.2 cfs (~5,000 gal hr^{-1}), while the maximum flow rate of 30–40 cfs (~one million gal hr^{-1}) occurred more frequently in 1991 (July, August) and 1992 (March, June, July) than in the early years. These high flow rates were directly related to intense periods of rainfall in the RFP area, represented by the arrows in Figure 5. The stream flow data are important for determining dilution of liquid effluents released from the RFP. The historic records show that liquid effluents from the RFP increased the natural stream flow of South Walnut Creek.

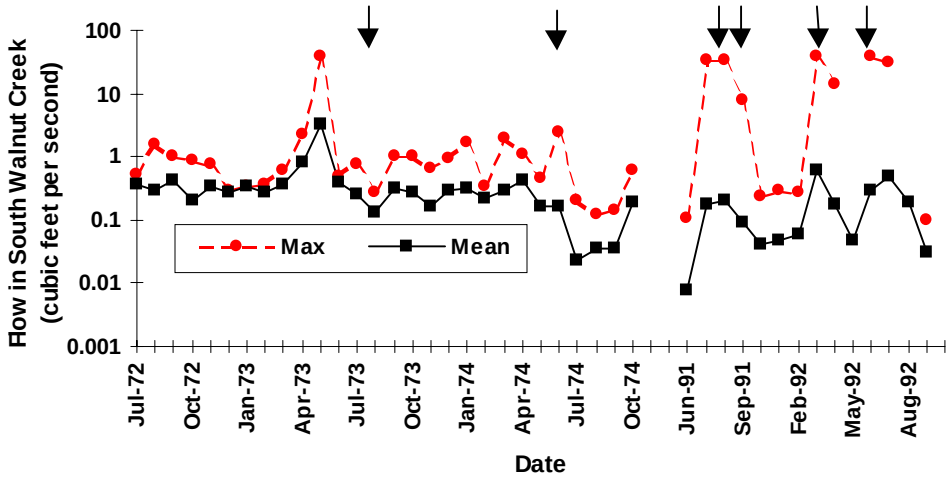

Figure 5. Comparison of maximum and average stream flow rates in South Walnut Creek in 1972–1974 and 1991–1992. The arrows represent months when at least one inch of rain fell in a 24-hr period.

The USGS determined that the Walnut Creek drainage contributed from 17% to 37% of the net drinking water supply for the City of Broomfield in the early 1970s (Zillich 1974). Of that percentage, the RFP Sewage Treatment Plant effluent contributed approximately 12%–16% of that volume (Dow 1969–1972). As a result, it was estimated that the Walnut Creek drainage basin provided approximately 2% to 5% of the annual volume of the GWR water source (Ofte et al. 1973, Hurr 1976). The Church Ditch drainage is the primary contributor of water to the GWR. Table 1 summarizes the inputs to the GWR from the Walnut Creek and the Church Ditch drainages.

Table 1. Water Inputs to the Great Western Reservoir[a]

		Contribution to GWR from:	
Year	RFP contribution to Walnut Creek (%)	Walnut Creek (%)	Church Ditch (%)
1970	14.1	17.5	82.5
1971	16.5	28.4	71.6
1972	11.7	37.3	62.7

[a] From Zillich, 1974; these values were based on calculating the amount of water in the reservoir, determining the amount pumped from other sources and subtracting the amount used by the City of Broomfield. The remainder was assumed to be the contribution of Walnut Creek drainage. Water lost through seepage and evaporation at GWR were not included.

The processing and waste handling activities at the RFP affected these local drainage streams. Prior to late 1974, the liquid effluent from the plant's sanitary-sewage disposal system was discharged directly into South Walnut Creek. From records in the early 1970s, the monthly sanitary sewer effluent volume for the plant averaged 6.8 million gallons (26 million liters) per month during 1971 to 1973, and produced continuous flow in South Walnut Creek (Table 2). These values represent only the discharges from the Sewage Treatment Plant; the total effluent volume from all sources, including the Sewage Treatment Plant, was higher. Backwash from the plant's water-supply filter system was also discharged into Woman Creek until 1975.

Table 2. Monthly Sanitary Sewer Effluent from RFP to South Walnut Creek for 1971–1973[a]

	Sanitary Sewer Effluent (millions of gallons)[b]		
Month	1971	1972	1973
Jan	7.47	6.56	5.96
Feb	6.38	6.84	5.41
Mar	6.99	6.62	6.23
Apr	7.43	6.95	7.39
May	7.90	6.82	7.05
Jun	7.35	6.98	5.34
Jul	7.55	6.59	5.33
Aug	7.51	6.91	4.91
Sep	8.44	6.37	4.68
Oct	6.68	6.92	5.50
Nov	6.55	6.47	5.10
Dec	6.80	6.60	5.48
Total	87.1	80.6	68.4

[a] From Hurr 1976; data supplied by Rocky Flats Plant.
[b] One million gallons = 3.8 million liters.

After 1974, the RFP maintained the stream flow gauging stations, but no daily flow records could be located for this project. However, annual summaries in some of the environmental monitoring reports provide annual flow values (e.g. Boss et al. 1973; Barker et al. 1981). In the spring of 1991, the stream gauging escalated greatly when the Event Related Surface Water

Monitoring Program at the RFP was established to support the environmental regulations put forth in DOE Orders 5400.1 and 5400.5, the Clean Water Act National Pollutant Discharge Elimination System Stormwater Discharge Permitting, and the Agreement in Principle between DOE and the State of Colorado (EG&G 1993b). A network of thirteen new gauging stations provided continuous flow monitoring data on Woman Creek, South Walnut and Walnut Creek, as well as on Smart Ditch, Rock Creek and Mower Ditch. The USGS assumed operation of the network in May 1993 (Clow and Johncox 1995).

DATA QUALITY AND STANDARDS FOR SURFACE WATER

Evaluating the results of the surface water monitoring data collected in the early years of operations provides perspective on the general trends of contaminants measured over time and at different locations that resulted from RFP operations. The approach in Phase II was has been to look at the inside of the facility, determine how effluent monitoring was handled, and with this knowledge, interpret the offsite environmental monitoring data. The historic offsite water monitoring data has been evaluated in a separate report (Rope et al. 1999). The quality of the measurement data and the regulatory standards in place in the early years of operations at the RFP are explored in this section.

Data Quality

At the RFP, laboratory logbooks provided data on quality control measurements in the 1950s. In 1974 a more rigorous quality control program was instituted to provide data on laboratory analysis performance.

Evaluating data quality means examining the collection, handling, and analysis of samples and checking the calculations of the final reported results against the original raw measurement data. Before standardized quality control procedures were established in the early 1970s, we tried to document how samples were collected and handled and how the laboratory analyses procedures were controlled and checked. We located site survey laboratory logbooks that listed the results of the collection and laboratory analysis procedures and results of environmental samples for 1952–1953, 1959–1960, 1962, 1969, 1970. 1971, 1972, 1974, 1975, 1979 (Dow 1952–1953, 1960, 1961, 1969–1972, 1974-79). These logbooks provided information on the laboratory procedures, calculations, routine sampling sites, and data quality checks that were done throughout these time periods. The 1952–1953 logbook noted that water sample collection began on February 27, 1952, and experiments relating to methods of analysis are documented. Water samples were filtered, pretreated with concentrated nitric acid, and digested, resulting in three fractions for analysis: a 10-liter portion, a 1-liter portion, and the residue. The efficiency factors and equations used in the calculation of activity levels were based on Hanford procedures, but were written out in the Dow logbooks (Dow 1952–1953, 1960, 1961, 1969–1972). The handwritten procedure in 1952 specified “a 45% overall efficiency” for water samples with example calculations provided. By 1959, the calculated efficiency was recorded as 43.4%. The data frequently recorded in these books were

- Sample number and location designation
- Collection, lab analysis, and report dates
- Sample size and analyst

- Count time
- Gross counts per minute (cpm)
- Background and blank measurements that were subtracted from the gross activity to give the net count rate
- Net cpm
- Process efficiency
- Disintegrations per minute (dpm) per liter
- Remarks.

Split samples were done regularly (usually biweekly), spike samples were done monthly, and all results were tabulated in the laboratory logbooks. These logbook calculations were checked and verified to show that the monthly averages reported in the routine reports were obtained from these daily logbooks. Samples that had concentrations below the minimum detectable concentration (MDC) values were considered as having the MDC for averaging values, tending to give an overestimate to measurement results (Allen et al. 1974). For the 1950s, the background count rate averaged 0.08 cpm, with a range of 0.03–0.25 cpm, and the count rate for the blanks ranged from 0 to about 0.18. The average gross count rate of offsite water samples ranged from about 0.30 to almost 100 cpm, depending upon the location.

In July 1974, "a rigorous analytical quality control program" was established in the Rocky Flats Environmental Analysis Laboratory. Estimates of variance and bias for standard sample analysis were reported in the annual environmental monitoring reports for the analysis of americium, uranium, plutonium and tritium in surface water. In October 1974, the U.S. Environmental Protection Agency (EPA) issued a water discharge permit to the RFP under the National Pollutant Discharge Elimination System permit program. This program established effluent concentration limits for nitrate, total nitrogen, phosphate, 5-day biochemical oxygen demand, fluoride, dissolved oxygen, residual chlorine, total suspended solids, fecal coliform bacteria, total chromium, oil and grease, and pH in the sewage treatment discharge. Table 3 summarizes the RFP environmental analysis laboratory performance for plutonium and tritium for the 1970s.

Regulatory Standards for Radioactivity in Water

The U.S. Public Health Service first adopted drinking water standards in 1914 "to protect the health of the traveling public." There were a series of revisions to those standards over time which were applicable to water supplies in general. With the development of nuclear energy and other technological advances, the standards were revised once again in 1962 to update the 1946 standards (PHS 1962). In the early years of operations at the RFP, the level of nitrates in wastewater was of special interest because of high levels of nitrates in liquid waste waters from the plutonium processing building. In 1962 the drinking water standards for nitrates was 10 mg per liter. For the first time, the 1962 revision of the Drinking Water Standards included limiting concentrations of radioactivity in water. In 1955, according to the Colorado Department of Health, the maximum permissible alpha activity to be discharged was 100 pCi per liter (Ryan 1955). For radioactivity in drinking water, numerical guides were given for ^{226}Ra (3 pCi per liter) and ^{90}Sr (10 pCi per liter) with the assumption that these levels were protective for other alpha and beta emitters, respectively (PHS 1962).

Table 3. Reported Performance for the Rocky Flats Plant Environmental Analysis Laboratory, Water Samples, 1974–1980[a]

	Plutonium			Tritium		
Year	Relative error[b] (%)	Bias[c] (%)	Total control analyses	Relative error[b] (%)	Bias[c] (%)	Total control analyses
1974	58.2	8.2	e	3.4	-5.4	e
1975	30.4	-12.4	48	5.7	-4.7	48
1976	22.2	21.5	48	7	-1	60
1977	70.6	25	60	5.3	-4.5	60
1978	54.7	29.7	30 [d]	7	-4	30 [d]
1979	-15.2	-23.2	60	-6.6	-8.7	60
1980	-10.0	[e]	60	-3	[e]	60

[a] Values from the annual environmental monitoring reports (Dow 1975; Rockwell 1976–1980; Barker et al. 1981).
[b] The ratio of the standard deviation of the 6-month differences to the average standard value in percent, that is, observed value minus standard value, divided by average standard value, times 100 equals the ratio as expressed in percent. In 1977, the ratio was based on a 12-month average. This term includes all random and systematic error in the standards analytical chemistry and measurement processes for a given radionuclide, media, and procedure.
[c] The six-month average bias in percent. A minus sign indicates a negative bias, that is, the values obtained were low. No sign indicates a positive bias, that is, the values obtained were high. In 1977, the bias was based on a 12-month average.
[d] For March to August 1978.
[e] Not reported in annual report.

In 1968, the Atomic Energy Commission (AEC) reported numerical guides governing the release of radioactive effluents and concentration standards for radioactivity in environmental samples (AEC 1968). For comparison to standards, all radioactivity in plant effluents and environmental samples at Rocky Flats were assumed to be soluble for purposes of comparison with the appropriate concentration standards (Table 4). This assumption was reported as an additional safeguard because guidelines for soluble radioisotopes were more restrictive than those for insoluble radioactive materials. These standards were reported in routine monitoring reports along with measurement values (Dow 1970).

Table 4. Historic Regulatory Guides for Releases of Constituents to Surface Water

	Standard (pCi L^{-1})		
Date	$^{239,240}Pu$	$^{233,234,238}U$	Natural uranium
1972-1980 (AEC 1968, ERDA 1974)	1600	10,000	40,000
1981 (DOE 1981)	1600	200	

In the mid-1970s, the Energy Research and Development Administration (ERDA) took over the regulatory responsibility for setting standards (ERDA 1974). The standards for plutonium and uranium in waterborne effluents remained the same as those promulgated by the AEC. Then in 1981, the DOE provided guides for radionuclide in ambient air and water borne effluents

(DOE 1981). These guidelines were accepted and implemented by the Colorado Department of Health. The standards for plutonium and americium were again the same as those listed above, but the applicable standard for uranium was lowered to 200 pCi L^{-1}.

For nonradioactive constituents in water, standards for chemicals and water quality standards were reported by the state health department in 1971 (CDH 1971). A water discharge permit was first issued to the Rocky Flats Plant by the EPA under the National Pollutant Discharge Eliminating System (NPDES) permit program in October 1974. The NPDES permit established effluent concentration limitations for nonradioactive pollutants; it established limits for nitrate, phosphate, 5-day biochemical oxygen demand, fluoride, dissolved oxygen, chlorine residual, total suspended solids, fecal coliform bacteria, total chromium, oil and grease, and pH in the sewage treatment plant discharge, and for nitrate and pH in the discharge from Holding Pond A-3 in Walnut Creek.

In 1976, the EPA provided regulations for radionuclides in drinking water (EPA 1976). These regulations, effective on June 24, 1977, were intended to ensure that each state had primary enforcement for maintaining drinking water quality. To comply with these requirements, the Colorado State Board of Health modified existing state drinking water standard to include radionuclides (CDH 1977). The state standard for gross alpha activity in community water systems was a maximum of 15 pCi L^{-1}. The alpha emitters, americium and plutonium were included in this limit.

PERSPECTIVE ON HISTORIC GROUNDWATER MONITORING

Periodic sampling and sample analysis of water from Rocky Flats groundwater monitoring wells began in 1960, when six monitoring wells were drilled to check for movement of contaminants from the solar evaporation ponds (Hoffman 1982; Blaha 1987). Table 5 provides key pieces of information on these and other early groundwater monitoring wells. In 1971, wells were drilled to determine if significant movement of radioactivity from the holding ponds had occurred, and to monitor the 903 Area after the asphalt pad was applied.

Table 5. Groundwater Monitoring Wells at Rocky Flats

Wells	Date	Casing Material	Study Area	Depth (ft)
60-series	1960[a]	galvanized iron	Solar evaporation ponds	~30
68 series	1971[a]	galvanized iron	903 Area	~ 4
71 series	1971[a]	steel	holding ponds	~ 22–30
74 series	1974[a]	plastic	holding ponds and burial sites	~13
85 series	1985[a]	PVC	Waste and drainage areas	~ 3–100
86 series	1986[a]	RCRA[c] specifications	various	RCRA
boundary; special purpose	1994[b]	RCRA specifications	Near eastern RFP boundary	RCRA

[a] From Hoffman (1982,1984), Blaha (1987).
[b] From EG&G 1994.
[c] RCRA = Resource Conservation and Recovery Act.

Prior to 1982, sampling of the groundwater was done at roughly five-month intervals. In 1982, quarterly sampling began and additional parameters were analyzed in order to comply with new requirements from DOE (Hoffman 1984). A major change in the groundwater monitoring program occurred in 1985 with the Resource Conservation and Recovery Act (RCRA), and 56 new monitoring wells were installed. Construction of RCRA-quality groundwater monitoring wells began in 1986 with the installation of 69 additional wells. In 1987, 53 more wells were drilled.

Historic monitoring results have been summarized previously (Hoffman 1982; Blaha 1987), and show localized areas of elevated radioactivity at or near past disposal sites, near the solar evaporation ponds and in the 881 Hillside area. Elevated nitrate concentrations are found in groundwater near the solar ponds and from the 881 Hillside. Volatile organic compounds have been measured in those areas, as well as near the 903 Area and near the former mounds burial area. With the RCRA program, extensive groundwater characterization studies are proceeding. At this time, these areas of contamination are within the plant boundary.

New monitoring wells continued to be added as groundwater issues took on more importance with cleanup operations underway. For example, 57 new wells were installed in 1994 in a spray field area near Indiana Street and near the present landfill (see Figure 3). By 1994, 352 of the approximately 700 wells at the RFP were regularly sampled for groundwater, including eight boundary wells located at the site's eastern boundary at Indiana Street quality (Kaiser-Hill 1994). In one well just west of the point where Walnut Creek crosses under Indiana Street, total (dissolved plus suspended) ^{239,240}Pu and total ^{241}Am were measured above background limits. In 1994, the highest reported activity for total ^{239,240}Pu in this well was 1.1 pCi L^{-1} in a sample taken February 21 and the highest ^{241}Am level was 0.29 pCi L^{-1} in a sample taken of February 16 (Kaiser-Hill 1994). Additional monitoring of these wells has continued.

This Historical Public Exposures Studies on Rocky Flats focused on past activities and the offsite release of contaminants from those historic operations. For this reason, further evaluation of groundwater as a potential exposure pathway for offsite populations during the period of interest for the dose reconstruction, 1952–1989, is not applicable to the current study. However, the groundwater exposure pathway may be important for future exposure scenarios, and current Actinide Migration Studies underway may help to characterize the chemical and physical form of plutonium at the Rocky Flats site and to define future potentially significant pathways

ONSITE LIQUID EFFLUENT HANDLING SYSTEMS

The processes for treating liquid wastes at the Rocky Flats Plant have been fairly simple, and have changed relatively little over the years. Normal effluents include radioactive and or chemical-contaminated liquids generated in several process areas, laboratories, laundries and decontamination areas. Figure 6 shows how liquid wastes moved through a series of pipes and holdings tanks before being discharged to either Building 995, the sanitary waste system; Building 774, the process waste treatment facility; the onsite solar evaporation ponds; or to the A-, B-, or C-series holding ponds.

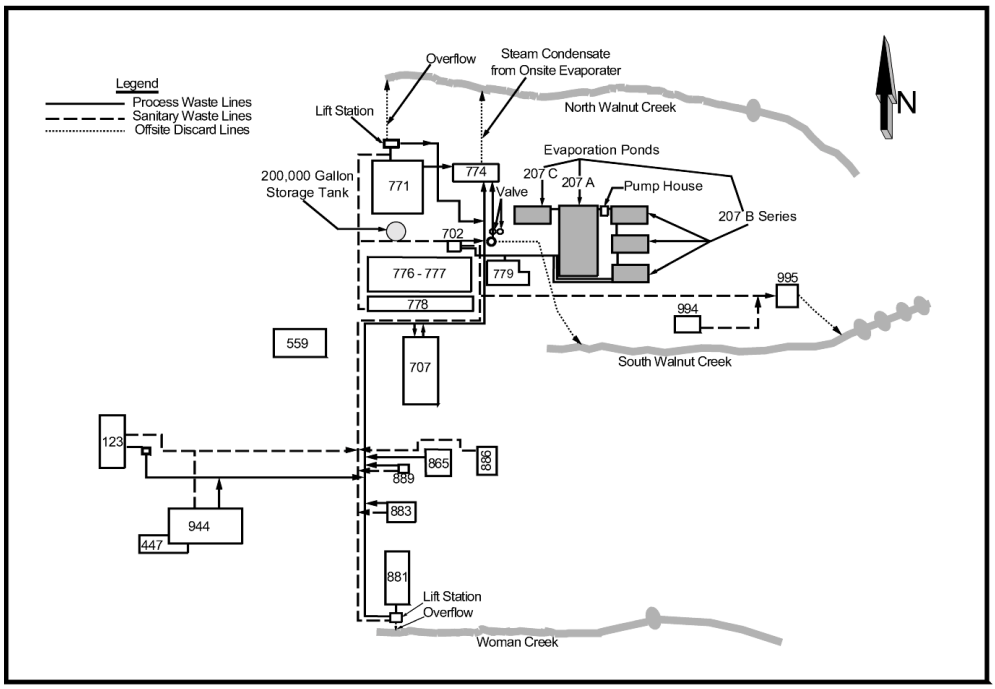

Figure 6. Liquid effluent piping and transfer system that was used from the 1950s through the 1970s (Love et al. 1970). The diagram illustrates the process waste lines that carried materials from process areas to the waste treatment facility in Building 774, the sanitary waste lines that carried effluent to the sanitary sewer treatment facility (Building 995), and the offsite discard lines that carried liquid effluent from Building 774 to North Walnut Creek, from Building 995 to South Walnut Creek, and overflow from the water treatment facility to Woman Creek to the south.

Table 6 summarizes the options that were available for pipeline transfer from operations in various buildings to particular onsite destinations (to Building 774, Building 995, the 200,000 gallon (760,000 liters) tank, or the solar evaporation ponds) or offsite via the holding ponds to Walnut Creek (Plock 1972).

Liquid Effluent Processing Buildings

Processing liquid wastes that were generated during production or support operations began with collection at or near the points of origin. Then the wastes were analyzed and categorized as:

- *Low chemical with low radioactivity* (neither chemical nor radioactive contaminants exceed existing standard for drinking water). These wastes were either transferred to Building 995 Sewage Treatment facility or drained directly offsite via Walnut Creek.
- *Either low or high chemical but high radioactivity.* Transferred directly to Building 774, or stored temporarily in a 200,000-gallon (760,000-liter) steel tank south of Building 774.
- *High chemical with low radioactivity.* These liquids were normally routed to the Solar Evaporation Ponds 207A and 207B, or they could be neutralized and evaporated instead.

Table 6. Liquid Effluent Pipeline Transfers at Rocky Flats Plant in the Early Years[a]

Building Source (Principal Contaminants)[b]	Waste Treatment (Bldg. 774)	200,000-Gallon Tank (Bldg. 774)	Sewage Treatment (Bldg. 995)	Evaporation Ponds 207A & 207B[c]	Offsite via Walnut Creek
123	X			X	
444/447 (U, Be)	X		X	X	
881/887 (U, Pu, Be, acids)	X		X [d]	X	
883 (U, Be)	X			X	
889	X			X	
865	X		X [e]	X	
559 (Pu, lab reagents)	X			X	
707 (Pu)	X		X [e]	X	
776 / 777 / 778 (Pu, Be, solvents, acid)	X	X	X [d]	X	X [d]
779 (Pu, Be, chemicals)	X	X		X	X [d]
771 (Pu process: Pu, Am)	X	X			
771 (labs)	X	X		X	X [d]
774 (Pu, Am, U, chemical)		X		X	X [d]
995					X

[a] From Love et al. 1970; Kittinger and Linck 1970.
[b] U = uranium, Be = beryllium, Pu = plutonium, and Am = americium.
[c] Beginning in August 1956.
[d] Valves must be unlocked by Health Physics personnel for shipment.
[e] Shipment controlled by removable spool piece in pipeline to Building 995, which was normally not in place.

Buildings 774 and 374 were the primary waste processing facilities onsite for handling liquid process wastes, although Building 374 was not operational until the early 1980s. The main features of the liquid process waste facilities at the RFP are summarized in Table 7. Building 774 was built in 1952 to support Building 771 by treating its radioactive aqueous waste. The aqueous waste treatment facility was a one-story building, 60 feet square. The facility was divided into two sections, with each section designed to accomplish one stage of decontamination. Outside the building were reinforced concrete tanks and a drum storage dock.

Table 7. Main Features of the Liquid Effluent Processing Facilities at the RFP[a]

Building	Operations began	Waste Streams[b]	Renovations
774 Process Waste Treatment Facility	1952	1. Radioactive aqueous 2. Organic liquids 3. Silver recovery from photo operations 4. Miscellaneous waste from laboratory operations	In 1963, 1965, 1966, 1967, 1970, and 1974; in 1981, it was converted to storage of drums for Building 771
995 Sewage Treatment Plant	1952-53	Some drains in manufacturing areas open to sanitary sewer resulting in some U and Pu directly to Walnut Creek; release of laundry waste to sanitary sewer stopped on in December 1973.	Tertiary treatment system completed in December 1974. Solids decomposed in anaerobic digester, and after drying, sent to Idaho in 55-gal drums.
Buildings 442 and 778 Laundry Facility	Not known	Clothing had radioactivity and Be. Room 127 contained the asbestos and Be laundry.	Initially, Buildings 881, 771, and 991 had laundry facilities; by 1958 Building 778 was laundry facility for all Pu facilities.
374 Process Waste Treatment Facility	1978	Wastes from Building 371 and to supplement treatment in Building 774; no silver recovery or organic liquids processed.	Designed to eliminate need for solar evaporation ponds; condensate from evaporator to cooling tower, then to Pond B-5 through 1989.

[a] From Owen and Steward 1974; ChemRisk 1992.

[b] Be = beryllium, Pu = plutonium.

The aqueous waste treatment process were divided into four phases: (1) first-stage processes, (2) second-stage processes, (3) evaporation processes, and (4) waste ponds. Table 8 shows that the second stage processing rate was much greater than the first stage. The first stage operation removed much of the radioactive materials through a continuous carrier precipitation process (Ryan et al. 1965). The second stage was a batch flocculation process. The plutonium-contaminated wastes were classified into four categories:

1. High salt basic wastes
2. Low salt basic wastes
3. High salt acidic wastes
4. Low salt acidic wastes.

Typical alpha activity of the waste was reported to be 1.8×10^{-1} microcuries per milliliter (μCi per ml), or 1.8×10^{5} pCi L^{-1} (Ryan et al. 1965).

Table 8. Building 774 Aqueous Waste Treatment Processes

Stage	Processing rate	Decontamination factor
First-stage processes	250 gal h^{-1}	200
Second-stage processes	17,000 gal d^{-1} = ~700 gal h^{-1}	200
Evaporation processes[a]	250 gal h^{-1}	10,000

[a] Design specifications in 1965 before evaporator was operational.

Liquid wastes entered the first stage by vacuum transfer, were neutralized and filtered, and the resultant liquid was transferred to either the neutral- or basic-waste process feed tank for further treatment. A ferric-hydroxide flocculant acted as a scavenger to remove radioactive contaminants from the waste stream. A slurry drain valve opened periodically to remove the slurry by gravity flow into the slurry tank. The supernatant liquid overflowed through a trough where the effluent was pumped to the second-stage process, which was basically a repeat of the first.

Both processes used a ferric-hydroxide carrier-precipitation method of decontamination. Liquid wastes meeting the drinking water standards were stored in unlined earthen ponds (holding ponds), while wastes meeting the radioactive contaminant standards for onsite storage, but not meeting the drinking water standards for the chemical contaminants were stored in asphalt-lined ponds (solar evaporation ponds) or shipped to Building 374 (after 1982).

An evaporator was installed and operated in Building 774 from 1965–1979 to treat the waste water in the solar evaporation ponds. The evaporator was not capable of handling the volume of liquid waste discharged and this limited capacity never did eliminate the need for the solar evaporation ponds. In the early 1980s, the liquid effluent from the stage two processing in Building 774 were transferred to Building 374. The chemicals used in the processing were nitric acid to precipitate plutonium and americium, caustics to adjust the pH, reagents such as ferric and magnesium sulfate, and flocculating agents. No organic solvents were used. Building 774 also processed organic liquid wastes from Buildings 776 and 707.

Building 374 became operational in 1980 to process wastes from the new plutonium recovery facility in Building 371. Processes were essentially the same as in Building 774, with the exclusion of the silver recovery and organic liquid waste treatment.

An evaporator operated in Building 774 from 1965 to 1979 to treat the liquids in the solar evaporation ponds. However, its limited capacity never did eliminate the need for the solar ponds.

At the sanitary waste facility (Building 995), daily logbooks recorded the volume of waste, its building and process origin (e.g. laundry water, evaporator condensate), pH, radioactivity, nitrate, and chromium concentrations (Dow 1970, 1973). The sanitary waste treatment plant was designed with a capacity of 450,000 gallons (1,700,000 liters) per day. Daily flows usually varied between 150,000 and 250,000 gallons (570,000 and 950,000 liters) per day. Before 1974, effluents from the sanitary sewer system were being discharged directly into Walnut Creek.

Holding Tanks

Most of the main processing facilities had one or more holding tanks for the effluents generated during processing. Tables A-4 and A-5 in Appendix A describe the holding tanks and ponds at the RFP. Building 776/777 had the greatest number of these tanks as well as tanks with the largest capacity (22,500 gallons [85,500 liters]).

The 200,000-gallon (760,000-liter) storage tank south of Building 774 was utilized for effluents with activities too high to discharge directly to Walnut Creek and too low to "warrant the cost of processing in 74 Building" (Ryan 1953–1971). Consequently, the waste waters were pumped into the 200,000-gallon (760,000-liter) holding tank and then released in small volumes through the Building 774-995 line to mix with the effluent from Building 995, the sewage treatment plant, to the retention ponds on South Walnut Creek.

Early liquid effluent operations included the discharge of some waste liquids directly to Walnut Creek. When Building 771 went into operation in 1953, certain waste liquids passed through a storm drain northwest of the building and drained into North Walnut Creek (Figure 2). These waste liquids came primarily from the Building 771 laundry holding tanks; other sources included the analytical laboratory, radiography sinks, the personnel decontamination room, and runoff from the roof of Building 771 and ground areas. Liquid waste from the laundry in Building 771 was collected in two concrete holding tanks with a capacity of 14,000 gallons (53,200 liters) each (Table A-4). If the plutonium concentration was less than 3300 dpm L^{-1} (1500 pCi L^{-1}) the effluent was discharged directly to North Walnut Creek. In 1957, waste lines were installed from Building 771 (key plutonium processing area) to Building 774 (process waste treatment building), and from Building 771 to below Building 995 (the sewage treatment plant) to allow the release of some effluents to South Walnut Creek. However, because of equipment problems and leakage, periodic releases of laundry and other wastes from these holding tanks continued until 1965.

The sanitary landfill was located at the west end of an arroyo that collected surface runoff water that flowed to Walnut Creek. During periods of high rainfall (for example, in May 1973), the "landfill" branch of Walnut Creek would back up into the landfill area (Figure 3). During most of the time, this tributary was dry. In September 1973, two earthen dams were constructed in the tributary to retain landfill seepage water after the accidental tritium release in April and May of 1973 (Allen et al. 1974).

Holding Ponds

The effluent flow from the RFP has been primarily to the east with holding ponds designed to hold water for a time before release to the offsite creeks. The holding ponds played an important role in liquid effluent handling, and had an impact on decreasing the levels of activity that were released to the creeks and ultimately to the reservoirs. Figures 7a, 7b, and 7c are schematic diagrams that show the changes in pond number and location over the years. From the 1950s to the 1970s, there was one pond on North Walnut Creek (A drainage pond), four ponds in sequence on South Walnut Creek (B-series ponds), and one pond (C drainage pond) on Woman Creek (Figure 7a). The other two figures show the addition of ponds on North Walnut Creek, South Walnut Creek, and Woman Creek in the mid-1970s and 1980s, and changes in their flow patterns. Table 9 summarizes general features of the ponds. The history of the holding ponds, the

site streams, and the offsite reservoirs (Great Western Reservoir and Standley Lake) has been described (ChemRisk 1992; Hurr 1976). Much of this information has also been summarized in the current Environmental Restoration Program documents for Operable Unit 3.

In the early years of operations, the ponds were usually full so that inflow and outflow were nearly equal. Figure 8 shows that the volume of effluent discharged from the final holding pond in the series to South Walnut Creek varied widely, especially in the early years. The average discharge volume ranged from 2–9 million gallons (7.6–34.2 liters) per month over this 20-yr. period. Figure 9 demonstrates that the effluent volume discharged from the site was approximately ten times lower than the USGS-measured stream flow.

Table 9. General Features of the Holding Ponds at the Rocky Flats Plant[a]

Ponds	Date Built	RFP Effluents Received	Area (acres)	Volume (acre-ft)	Direction of Flow
None from 1952-1953		From 1952-1953, liquid waste containing nitrates, Pu and U discharged directly from plant to Walnut Creek			Walnut Creek→GWR
North Walnut Creek					
A-1	1953	Until 1957, untreated low-level waste; in 1957, waste rerouted to process waste treatment facility (Building 774).	1.13	6.23	To Walnut Creek→GWR
A-3	1971	Runoff from northern portions of plant for hold-up prior to discharge			To Walnut Creek→GWR through 1980; after 1980 to Pond A-4 →Walnut Creek→GWR
A-2	1973	From Pond A-1			Evaporation and sprayed
A-4	1980	From Pond A-3 and B-5			To Walnut Creek→GWR
South Walnut Creek					
B-1	1952	Sewage treatment plant effluent and laundry wastewater	0.30	0.57	To B-2
B-2	1950s		0.58	1.95	To B-3
B-3	1950s		0.53	1.90	To B-4
B-4	1970		0.42	1.78	To B-5
B-5	1980				To South Walnut Creek→GWR
Woman Creek					
C-1		Prior to 1975, backwash from the plant's water-supply filter system	0.80	1.80	To Standley Lake
C-2	1980	From South Interceptor Ditch			Pumped through the Broomfield Diversion Ditch to Big Cry Creek

[a] From Hurr 1976, Love et al. 1970, and ChemRisk 1992.

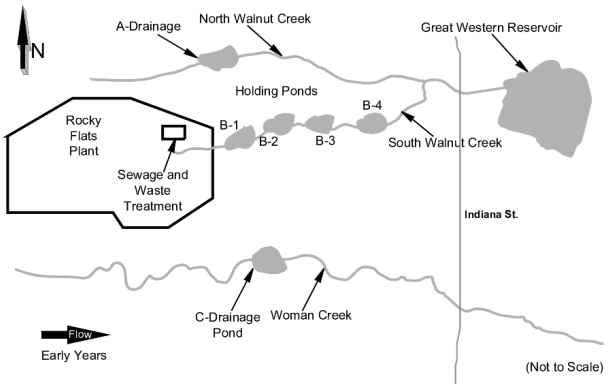

Figure 7a. Simplified diagram of the liquid effluent flow and holding ponds system at the Rocky Flats Plant in the 1950s and 1960s. This figure is not to scale.

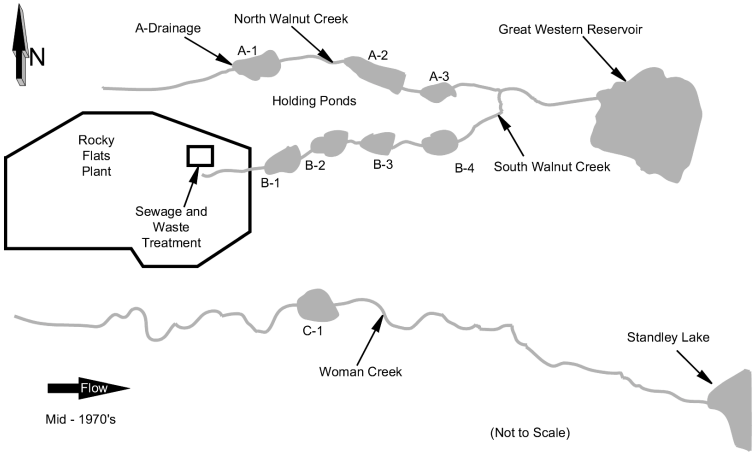

Figure 7b. Liquid effluent flow and holding ponds system at the Rocky Flats Plant in the mid-1970s. This figure is not to scale.

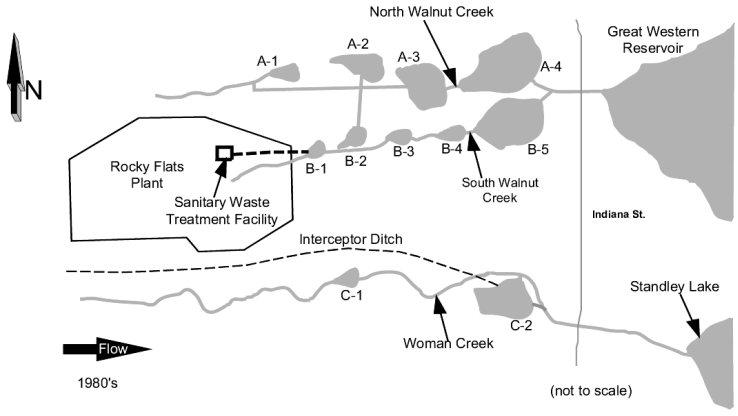

Figure 7c. Simplified diagram of the liquid effluent flow and holding ponds system at the Rocky Flats Plant in 1980s. This figure is not to scale.

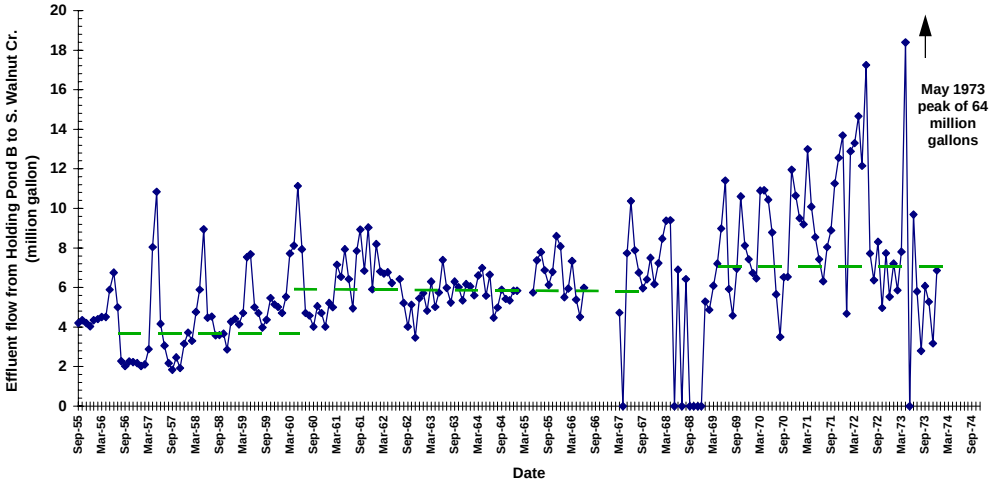

Figure 8. Average volume of effluent discharged from the RFP through Pond B to South Walnut Creek from 1952 through 1974. The monthly median volume, shown as the dashed lines, was 4.2 million gallons (16 million liters) in the 1950s, 6.2 million gallons (23.6 million liters) in the 1960s, and 8.2 million gallons (31 million liters) in the 1970s. Heavy rainfall and runoff occurred in May 1973, causing a record-setting average monthly flow of 64 million gallons (243 million liters).

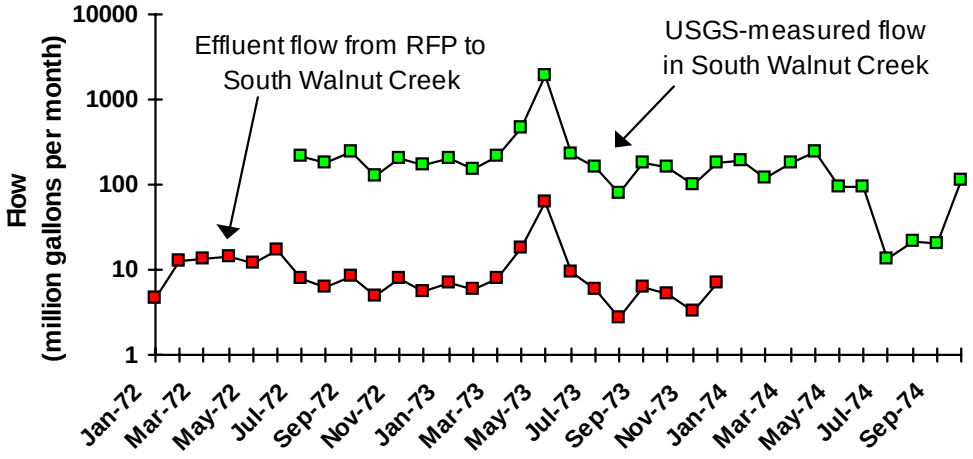

Figure 9. Comparison of the average volume of effluent discharged from the RFP through Pond B to South Walnut Creek from 1972 through 1974 with the average stream flow measured by the USGS in South Walnut Creek. This illustrates that about 10% of the volume of water in South Walnut Creek originates from RFP effluents.

The process liquid wastes released offsite via the B-series ponds were

- **Treated waste from Building 774** represented roughly 25% of the total process liquid waste released to the B-series ponds. The process waste liquids were pumped from production buildings to Building 774 where they were treated to reduce chemical and radioactive content to appropriate standards (in the early years, those standards were established by the US Public Health Service, PHS). When the standards were met, the waste was pumped to the final B-series ponds for offsite release to Walnut Creek. There was no constant release rate because releases were dependent on the workload, the amount of untreated liquid waste released and the amount of treatment required. Releases varied from 25,000–300,000 gallons (95,000–1,140,000 liters) per month.
- **Untreated waste from Building 771** represented only 1–2% of total process liquid waste released to the B-series ponds. The effluents that met the PHS drinking water standards (PHS 1962) for radioactive and chemicals contaminants were released directly to the pond (Pond 3 prior to 1975). The remainder was pumped to Building 774 for treatment.
- **Untreated waste from Building 779** represented just 4% of total process liquid waste released to the B-series ponds from RFP in the early years of operations. The wastes that met the drinking water standards were released directly to the pond (Pond 3 prior to 1975), while the remainder was pumped to Building 774 for treatment.
- **Liquid waste from Building 995 (sewage treatment plant)** accounts for the largest fraction of the volume of effluents released to the B ponds. Roughly 70% of total process liquid waste was released to B-series ponds from RFP. Liquid process wastes from other buildings that were to be released untreated were processed along with plant sanitary wastes at Building 995 and were released through here. The effluent then flowed to the first B-series Pond (Pond 3 prior to 1975).

Solar Evaporation Ponds

There were other onsite ponds for storage of liquid effluents, called the solar evaporation ponds (Table 10) that served a different purpose than the holding ponds near the original site boundary. The solar evaporation ponds were originally intended to store and allow the evaporation of (1) low-level radioactive process wastes that had high nitrate concentrations and (2) treated acidic wastes (EG&G 1991).

Initially, there appeared to be concern about the release of high levels of nitrates from the site. One of the first activities of the Waste Disposal Unit at the RFP, organized under the authority of John Epp at the direction of F.H. Langell in January, was obtaining “a list of periodicals pertaining to the effects of inorganic nitrates in drinking water on the human body,” prepared by the Denver Public Library (Ryan 1953–1971). Farrell and Ryan from the RFP visited the Midland plant in Michigan in February 1953 to search for information about the physiological effects of nitrates on man and animals. The Midland Waste Disposal Department in Michigan provided a list of publications on industrial waste treatment and disposal for reference and technical value. Later, the treatment and elimination of high nitrate content liquid wastes was the subject of a meeting held in Building 771 in March 1953, and in April of 1953, E.S. Ryan

attended the School for Water and Sewage Plant Operations at the University of Colorado for a week (Ryan 1953–1971).

Table 10. Contrasting Features of Holding and Solar Evaporation Ponds

Holding Ponds	Solar Evaporation Ponds
Unlined, clay-lined	Clay-lined (1954-55) Asphalt-lined (Aug 1956)
"Low chemical-low radioactivity"	"High chemical-low radioactivity"
Designed for storage & offsite release	Onsite storage & evaporation
Major renovation and rechanneling in 1972	Series of modifications from 1960 onward

A program of analyzing the waters of the GWR was initiated in April 1953 (Ryan 1953–1971), to "furnish a picture of the chemical content of the GWR before the release of any processed liquid-waste effluent from the plant site." On December 14, 1953, Dr. C.C. Ruchhoft of the U.S. Environmental Health Center, Cincinnati, Ohio, visited RFP to view and discuss various problems arising from the operation of the water treatment plants. Among the problems covered was the toxicity of nitrates "to adults and animals". After reviewing the effectiveness of the retention ponds on South Walnut Creek and the nitrate level of the effluent released from the lower pond, he "felt that there should be no danger to livestock using the effluent." He agreed that literature on the toxicity of nitrate to adult humans was lacking, but that the use of the solar evaporation pond for high nitrates liquid wastes was the answer for disposal of this type waste (Ryan 1953–1971).

The onsite solar evaporation ponds were constructed primarily because of concern about high nitrate levels being released offsite.

In June 1954, a test well dug near the northeast corner of the nitrate (unlined evaporation) pond gave no moisture at depth of 16 feet. However, a spring on the north slope of the mesa towards Walnut Creek showed nitrate content of 540 ppm. "This leads one to believe that a large portion of the nitrate waste has been dispersed through seepage into subsurface waters" (Ryan 1953–1971). William N. Gahr, Director of Division of Sanitation, Colorado State Department of Public Health, visited the site on October 28, 1954 to tour the Water Treatment and Sanitary Sewage Treatment Plants and to view the retention ponds. A monthly report indicates that he "expressed satisfaction with these operations." According to Gahr the maximum permissible alpha activity to be discharged was 0.1 pCi mL^{-1} (Ryan 1953–1971).

By the spring of 1955, it was clear the "present earthen pond in use is not water-tight and allows nitrate-contaminated water to seep to underground water courses." RFP directed the replacement of this initial solar pond (designated Pond 2 in monthly waste disposal reports at that time) with a "water-tight pond" (Ryan 1955). Consequently, the first clay-lined pond which had a maximum of two containments measuring 100×200 feet and 200×200 feet, respectively, was operated until 1956 when the new solar evaporation pond was constructed.

The first solar "water-tight evaporation pond" was put into service on August 31, 1956 to store and evaporate low-level radioactive process water containing high concentrations of nitrates and treated acidic wastes (Farrell and Ryan 1957). It had a surface area of 3 acres and a working capacity of 15 acre-feet. The solar ponds were initially asphalt-lined, while the holding ponds (A, B and C series) were unlined. Up to that time, half of the decontaminated liquids went to the B holding pond in which seepage and infiltration of liquids would occur. The asphalt evaporation pond was constructed to prevent seepage or infiltration of liquids with higher contaminant levels.

In July 1955, when newly-constructed homes in the Broomfield Heights area were to use the domestic water supply coming from the Great Western Reservoir, the state health department and the RFP knew it was necessary to retain wastes containing high nitrates, which violated the Public Health Service Drinking Water Standards.

Pond 207C was constructed to provide additional storage capacity and enable the transfer and storage of liquids from the other ponds in order to perform repair work on them. Pond 207C stores low-level radioactive liquid process wastes prior to evaporation, treatment and solidification in Building 374. The resulting sludge and sediments from 207A and B were removed periodically and disposed of at the Nevada Test Site.

As technology improved through the 1960s and 1970s, the solar evaporation ponds were relined with various upgraded materials; however, leakage from the ponds into the soil and groundwater was detected. Table A-6 in Appendix A provides descriptions of the solar evaporation ponds and details of the modifications that have been made. During repairs in the early 1970s, four-inch diameter underdrains were installed at the 207B ponds. These underdrains were laid so that any waste leaking through the asphalt concrete would be collected in these drains, which drained toward the northeast corner of the 207B Ponds where a sump and pump system was designed to return the water to 207B North. These interceptor trenches were installed in the early 1970s to collect and recycle groundwater contaminated by the ponds and to prevent natural seepage and pond leakage from entering North Walnut Creek. Only 207B north solar evaporation pond received contaminated water from the interceptor system in 1992 (EG&G 1993b).

The five solar evaporation ponds: 207A , 207B series (north, center, south). and 207C were used from the late 1950s until 1986. Modifications to the linings of the solar evaporation ponds have been made since the original construction because of cracking and slumping of the existing linings and leakage of pond contents.

In 1977 all the 207B ponds were cleaned of sludge. After the 1977 cleanout, the 207B solar ponds have not contained process waste. Six interceptor trenches and a "French drain" system (Rockwell 1983), constructed in the 1970s on the hillside north of the solar ponds, were designed to prevent natural seepage and pond leakage from entering North Walnut Creek. Trenches 1 and 2 were installed in October 1971, Trench 3 in September 1972, Trenches 4 and 5 in April 1974, and Trench 6 in July 1974. Trench 5 drained by gravity to Trench 4. Trench 4 pumped water to Trench 3, and Trench 3 returned the water to Pond 207A. Trenches 1 and 2 pumped water uphill into Sumps 1 and 2, respectively. The six trenches were taken out of service when the current French drain system became operational.

In the early years, liquid wastes meeting the drinking water standards for nitrates (in 1962, it was 10 mg L^{-1}) were stored in the unlined earthen ponds (holding ponds), while wastes meeting the radioactive contaminant standards for onsite storage, but not meeting the drinking water standards for the chemical contaminants were stored in the asphalt-lined solar evaporation ponds. In 1955, according to the Colorado Department of Health, the maximum permissible alpha activity to be discharged was 0.1 pCi mL^{-1}.

ONSITE LIQUID EFFLUENT MONITORING PRIOR TO 1970

Liquid effluent samples from the RFP were collected and analyzed since 1953. However, the extent of the monitoring program, the spatial distribution of sampling and the types of materials measured were fairly limited until the early 1970s. Under the auspices of the Waste Disposal Unit, the Water Laboratory, which was part of the General Laboratory at the site, conducted the analyses. The major focus of the analysis in the 1950s was on monitoring total solids and nitrates. There was always an effort to remove or reduce the nitrate content of liquid wastes because of the potential toxic effects on the local environment (Ryan 1953–1971). For more details, Table A-7 in Appendix A highlights the effluent monitoring history at the RFP. Tables 11 and 12 summarize the effluent sampling locations in the early years and the frequency and sampling methods that evolved over time.

Table 11. Liquid Effluent Sampling Locations

Building 771	To Walnut Creek	1953-1954
(plutonium processing)	To Pond A-1	After 1954
	To Walnut Creek from Pond A-1	After Feb 1955
Building 774	To South Walnut Creek	1953
(waste processing)	To B ponds	After 1954
	To South Walnut Creek from final Pond B	After 1954
Lift station	To Woman Creek	After May 1954
(near Building 881	To Pond C-1	After Mar 1955
	To Woman Creek from Pond C-1	After Mar 1955

Table 12. Liquid Effluent Monitoring Activities

Date	Sampling Activity and Frequency
Jul 1953	Began sampling the retention ponds on North and South Walnut Creek for gross alpha; no recording flow meter, volumes estimated. B pond–weekly composite of twice a day grab samples. A pond-grab sampled 2 times per day, 3 days per week.
Nov 1954	Temporary Parshall flume installed at B pond to measure effluent flow.
Aug 1955	Crude continuous sampler installed at B pond outlet, collected 50-gallon (190-liter) sample over a 24-hour period.
Feb 1956	Approval given for the housing structure, metering device and proportional sampler for Pond B-3; called Facility 207.
Aug 1956	Facility 207 operational.
By mid-1970s	Waste sampled continuously; collected daily from outfalls at B-4 and C-1; daily samples composited weekly for analyses.
By the 1980s	Plutonium and uranium isolated by ion exchange chromatography and detected by alpha spectrometry; total alpha by liquid scintillation (Bokowski 1974).

By the early 1970s, all effluent streams leaving the site were sampled (A-, B- and C- series ponds). Water was monitored continuously, and samples (including grab samples) were collected daily from the sewage treatment plant influent and effluent, and from Ponds A-3, B-4 and C-1. Continuous sampling was also done downstream where Walnut Creek crossed under Indiana Street (Hornbacher and Barker 1975). The sample preparation and analytical procedures were fairly well documented, and modifications were made in 1972 and in 1978. Table 13 briefly reviews the water collection and analysis procedures, and major changes that occurred.

Offsite water sampling was conducted at the GWR and Standley Lake. In Phase I, ChemRisk compiled much of the routine water monitoring data that had been collected by the site contractor from 1952 through 1970 and by the Colorado Department of Health and local communities from 1970 through 1989. Results of the water monitoring activities offsite are summarized in Phase II report for this project, *Evaluation of Environmental Data for Historical Public Exposures Studies on Rocky Flats*.(Rope et al. 1999). In later years, specific isotopic analyses were done by both the site contractor, the Colorado Department of Health and local communities.

Gross Alpha Measurements

The main period of interest for the Rocky Flats dose reconstruction project is prior to the early 1970s, the period during which the major releases of plutonium occurred. Except for special circumstances, only gross alpha measurements were made for routine liquid effluent monitoring prior to 1970. There was generally no monitoring of plutonium, beryllium, or organic chemicals during this time, even though laundry wastes from Building 71 and effluents from the sanitary sewer system were being discharged directly into Walnut Creek until 1974.

Backwash from the water filtration system, that is water from the washing of the water treatment tanks, was discharged directly to Woman Creek until 1975. This backwash water would have been contaminated with materials that had been filtered from the water treatment tanks. In 1971, this amounted to approximately 270,000 gallons (one million liters) of backwash

water per month. The backwash passed through the west side of the plant burn pit which received ashes from the plant incinerator before it flowed down to Woman Creek (Ryan 1953–1971).

Table 13. Water Monitoring Sample Collection and Analysis [a]

Sample Collection and Treatment	Laboratory Analysis Procedures
1952–1972: "Grab" samples; samples transported to lab, acidified with nitric acid, filtered, evaporated under infrared heater.	**1952–1962**: Diethyl ether extraction removed plutonium, uranium, and 40% of naturally occurring thorium isotopes; evaporated, counted in low-background gas-flow proportional counter. Alpha designated "gross alpha." Whenever anomalous alpha readings seen, pulse height analysis was done. **1962–1972:** Trioctylphosphine oxide (TOPO) replaces diethyl ether in extraction step.
1972–1978: Untreated sample composites were treated with hydrochloric acid and hydrogen peroxide, concentrated by evaporation. Great Western and Standley sampled daily, composited weekly for analysis.	**1972–1978:** Plutonium and uranium extracted together from concentrated samples with TIOA (triiosoctylamine), stripped from TIOA sequentially, and purified by ion exchange; americium separated, purified by cation exchange.
1978–1981: Intact samples concentrated by evaporation, residues wet-ashed with nitric acid.	**1978–1981**: Composite samples of untreated water evaporated, actinides purified by ion exchange-solvent extraction.

[a] From Bokowski et al. (1981); Thackeray (1953).

After effluent was released to the site streams, the holding ponds were designed to allow material to settle out before discharge to offsite streams and reservoirs. Annual average gross alpha concentrations are shown for Pond A-1 for 1952 to 1970 in Figure 10. The figure shows the effect that the holding pond had on the level of alpha activity released offsite to North Walnut Creek. Initially, effluents with alpha concentrations of 50 to 200 pCi L^{-1} were being discharged directly to North Walnut Creek. After Pond A-1 held the waste for a time, the levels of alpha activity discharged to the creek dropped ten-fold to about 10 pCi L^{-1}.

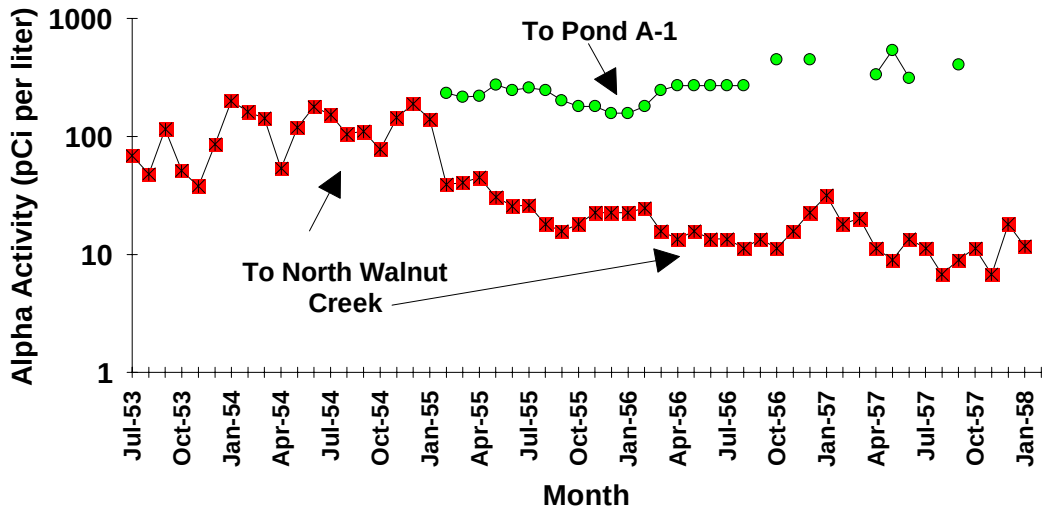

Figure 10. Gross alpha activity in liquid effluents from Building 71 to North Walnut Creek. Until early 1955, all Building 771 effluent went directly to North Walnut Creek. After the first holding pond A was open, the effluents flowed into the holding pond where material was allowed to settle out before discharge downstream.

Figure 11 is a similar graph for the alpha activity in liquid effluents from the Waste Processing Building 774 to the B ponds and South Walnut Creek. The releases to the B pond, shown from August 1953–August 1958, were somewhat more uniform than those to the A pond. It is clear, however, that the alpha concentrations were higher and much more variable prior to 1954 and the completion of the B ponds. Again, the alpha activity decreased from over 100 pCi L^{-1} to an average of 10 pCi L^{-1} after the effluents were held up in the ponds before discharge.

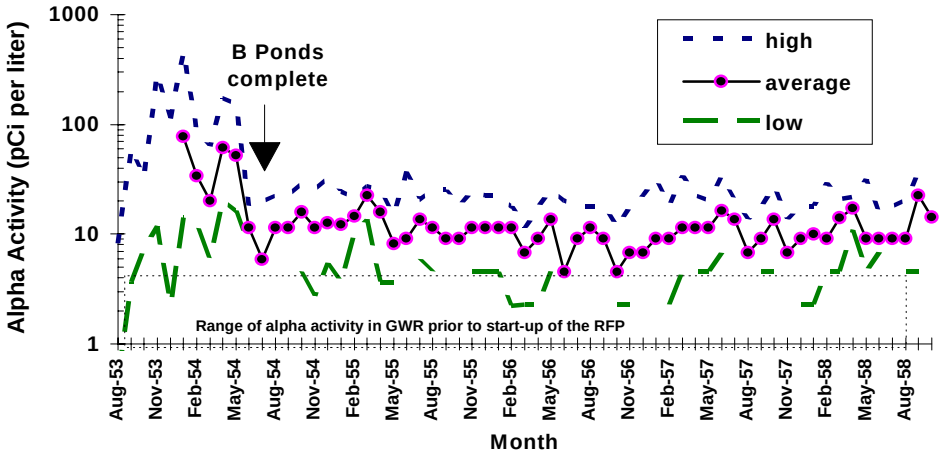

Figure 11. Alpha activity in effluent discharged to South Walnut Creek. Before June 1954, the effluent from the waste processing Building 774 went directly to South Walnut Creek. After the B ponds were operational, the effluent went to the holding ponds first. The dotted lines at 1 to 3 pCi L^{-1} represents the range of alpha activity values measured in the GWR in 1951, before operations began at the RFP.

Liquid effluent releases from the Rocky Flats Plant were reported monthly beginning in 1954 and daily logbooks for some years helped to confirm the values reported in them. The alpha activity released each month tracked the effluent volume fairly well, except in the last half of 1969 (Figure 12). This observation may be related to the 1969 fire in Building 776-777 and an effort to control the releases of contaminants from the site. The water used in fighting the fire that was trapped in pits under equipment and stairwells went to the process drains leading to underground storage tanks. It was reported that all water from the fire was transferred to the waste treatment facility (Joshel 1971).

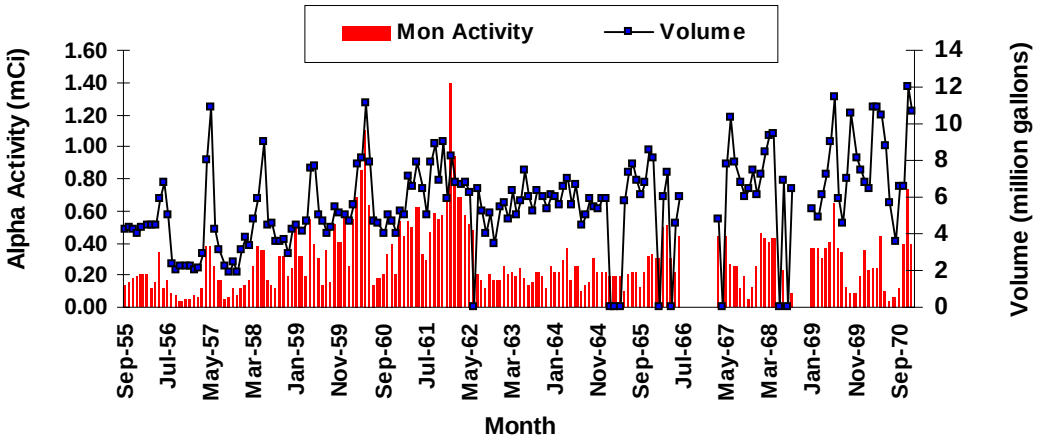

Figure 12. Liquid effluent releases reported from the Rocky Flats Plant. The bars represent the alpha activity and the line records the total volume released to South Walnut Creek for that month.

Plutonium-Specific Measurements

The concentration of plutonium released from the holding ponds to Walnut Creek decreased a hundred-fold during the 1970s.

Partially as a result of the May 1969 fire, the routine analyses of effluent and environmental water samples for plutonium began in September of that year. The focus of the current Historical Public Exposures Studies on Rocky Flats has been on evaluating the effluent monitoring program prior to 1970 in order to determine whether it would be possible to estimate quantitatively the amount of plutonium discharged from the RFP in liquid effluents. However, plutonium-specific measurements were made routinely only after 1970 (prior to that time, only alpha activity was measured). It was soon discovered that both plutonium-specific and gross alpha measurements were made concurrently for a three-year period, 1970 through 1973. This situation provided one method to estimate plutonium releases for earlier years when only gross alpha was measured. *RAC* approached the problem of better characterizing releases of plutonium in liquid effluents in the early years (before 1970) by correlating the alpha and plutonium-specific measurements that were done concurrently on water from Pond B-4 to

South Walnut Creek. Figure 13 illustrates that the gross alpha measurements for this time period track the plutonium-specific measurements well, with a correlation coefficient of 0.76. The monthly average concentrations are tabulated in Table A-8 in Appendix A.

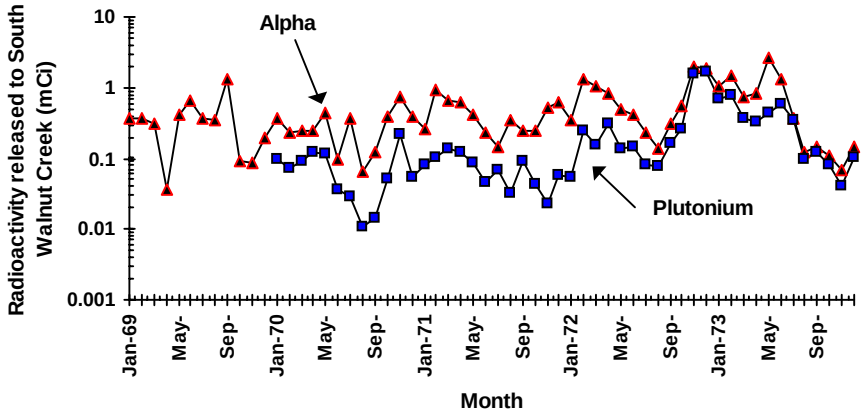

Figure 13. Comparison of estimates of release of gross alpha and plutonium from Pond B-3 to South Walnut Creek from January 1970 through December 1973. The estimates are based on monthly average concentrations and effluent volume measurements.

When this method is used, the result is a ratio of monthly plutonium to alpha activity of 0.37 with a standard deviation of 0.24 (median is 0.33). This ratio was then applied to measurements of alpha activity released from the same location from 1952 to 1970 (when plutonium was not measured). Sources of uncertainty were considered for applying the ratio to the alpha release estimates using Monte Carlo techniques in the Crystal Ball® program (Decisioneering 1993). The monthly plutonium release estimates, with 5th and 95th percentile values, are listed in Table A-9 in Appendix A.

The median monthly plutonium releases varied considerably with a range of 0.03 to 0.1 mCi. There were several months when releases exceeded 0.3 mCi (January 1954, May 1960 and January 1962) (Figure 14). In 1961–1962, higher than usual releases through the B ponds can be attributed to problems that arose when the process waste transfer line in the area of the Building 777 was relocated because of new construction south of that building. During excavation of the waste line, a flange was broken which allowed liquid waste to be released into an open trench (Ryan 1953-1971). By 1963, the first renovations to the Process Liquid Waste Facility (Building 774) were completed, and plutonium releases decreased.

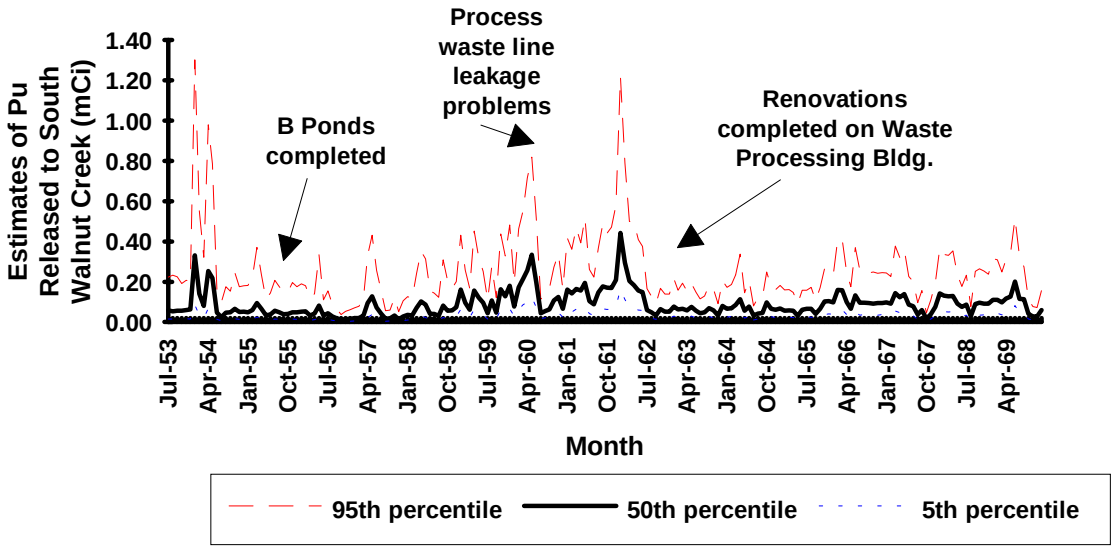

Figure 14. Plutonium release estimates from Pond B-4 to South Walnut for 1953 through 1969. The estimates are based on ratios of plutonium to alpha activity measured concurrently from 1970–1973.

This method allows some bounding of the amount of plutonium released to South Walnut Creek from the B ponds in the early years. Based on this ratio method, the total plutonium released from the B ponds to South Walnut Creek through 1969 is estimated to be 20 mCi (90% confidence interval of 6 to 55 mCi).

There are limitations to this method since it relies on measured releases to South Walnut Creek only and may not account for all losses to those ponds. Furthermore, this method does not account for plutonium discharged from the A holding ponds to Walnut Creek, although most of the liquid processing wastes were discharged through the B ponds to GWR. Nevertheless, these studies are important because they can contribute information to support the inventory estimates made for plutonium in sediment in the GWR. Studies by Schoep and Whicker (1995) from Colorado State University have estimated plutonium inventories in the GWR of 50 to 90 mCi through 1995 (Rope et al. 1999). They further estimated that approximately 87% of the plutonium in the GWR was deposited through aquatic inputs (44–78 mCi), with Walnut Creek as the likely primary source (Schoep and Whicker 1995).

Figure 15 compares the estimate of total plutonium released by the RFP in surface water to Walnut Creek through the B ponds through 1969 with the inventory of plutonium in sediment in GWR from aquatic releases. The estimates agree quite well, considering the limitations of estimating plutonium releases to South Walnut Creek in the early years from the ratio of plutonium to alpha activity measured over a three-year period.

The concentration of plutonium released from the holding ponds to Walnut Creek decreased a hundred-fold during the 1970s.

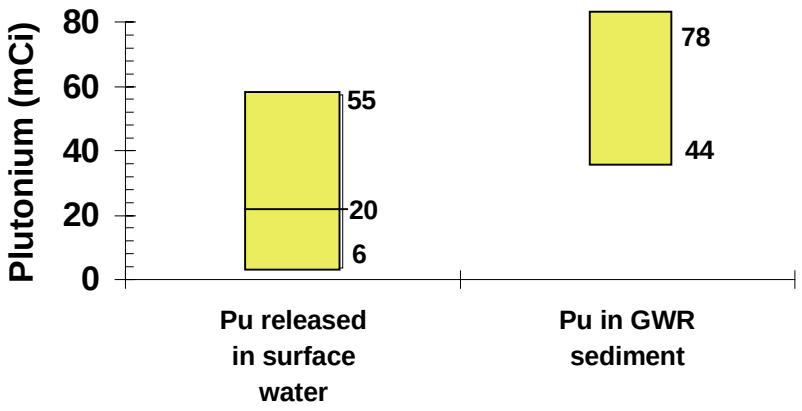

Figure 15. Comparison of the median estimate of plutonium released in surface water from the B ponds to Walnut Creek from 1952 through 1969 with plutonium in sediment inventory estimates from the studies of Schoep and Whicker (1995). They estimated that 87% of plutonium in GWR sediment came from the surface water.

After 1970, plutonium was measured routinely in effluent streams and in the holding ponds. Figure 16 shows the measured plutonium concentrations measured in the final holding ponds on North Walnut Creek (A-3 and A-4), South Walnut Creek (B-4 and B-5) and Woman Creek (C-1). In 1981, Ponds A-4 and B-5 were constructed to receive effluents from Ponds A-3 and B-4, respectively, prior to discharge to the creeks. The figure reveals that the concentrations of plutonium discharged from the site decreased dramatically in the late 1970s. In the B ponds, the annual average Pu levels decreased from 15,000 fCi L^{-1} (15 5 pCi L^{-1}) in 1972 to 5 fCi L^{-1} in 1989. Results of plutonium concentrations measured in offsite water are evaluated and presented in the Task 4 report (Rope et al. 1999).

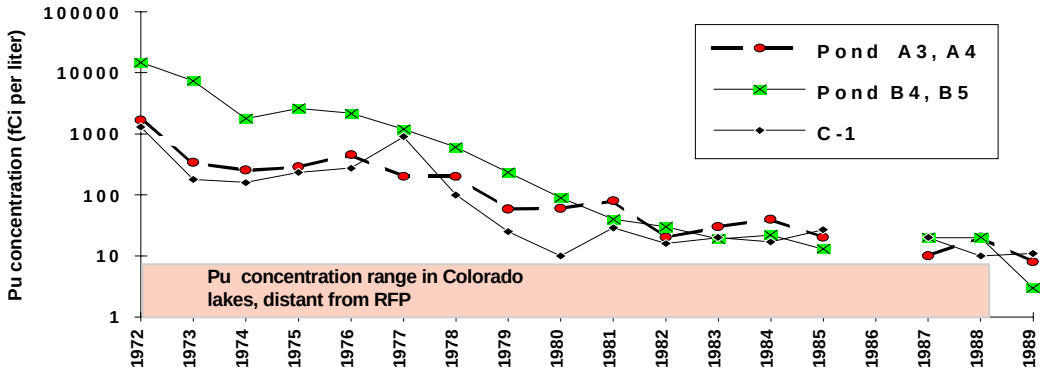

Figure 16. Comparison of annual average plutonium concentrations in water from the final holding ponds at the RFP from 1972 through 1989. The A and B Ponds discharged to Walnut Creek, then to the GWR. The C Ponds on Woman Creek flowed into Standley Lake. A femtocurie (fCi) is equal to 1000 picocuries (pCi). The range of plutonium concentrations in Colorado lakes is shown. Appendix B provides more information on background levels of plutonium in surface waters.

Pond Rebuilding

Extensive water and sediment monitoring was done from 1971 to 1973 in conjunction with a research project directed by Colorado State University to study the movement of plutonium in the aquatic systems of the RFP (Johnson et al. 1974). These data may be useful for estimating plutonium inventory in sediments in the GWR at a later time. Hundreds of water samples were taken from the various ponds during this 3-year time period, which included the pond reconstruction activities by the site. Furthermore, plutonium-specific measurements were made, along with total alpha activity. The measurements clearly showed that rebuilding the ponds resulted in an increase in plutonium concentrations in unfiltered water, probably from an increase of suspended particulate matter in the pond chain. Figure 17 illustrates the impact of the holding pond reconstruction activities on levels of alpha activity discharged to the GWR. Levels of alpha activity in water from Walnut Creek at Indiana showed a significant increase from about 10 pC L^{-1} in 1970 and 1971 to a high of almost 800 pCi L^{-1} in March 1973. By June 1973, alpha activity levels had returned to those measured before the pond reconstruction.

TRITIUM MONITORING

Tritium monitoring has proven to be valuable at the RFP, not because tritium processing and releases were extensive, but because the Colorado Department of Health (CDH) environmental monitoring program first detected a major release of tritium from the site. At the time of the actual release in 1973, tritium in Walnut Creek at Indiana Street was being monitored only by CDH. It is an example of how useful environmental monitoring can be in detecting or verifying site releases.

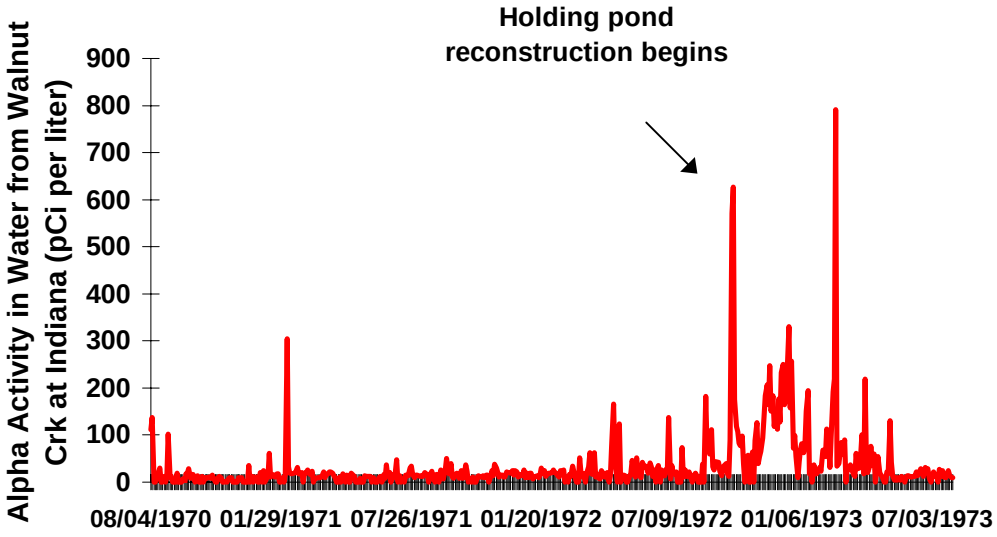

Figure 17. Weekly gross alpha activity in water collected by the Colorado Department of Health from Walnut Creek at Indiana Street from 1970–1973. The reconstruction of the A-ponds resulted in resuspension and release of materials in sediments and increases in weekly alpha activity up to 200 to 800 pCi L^{-1} during the pond reconstruction.

Tritium has been released accidentally from the RFP on several occasions. These incidents have been described in a number of reports (Dow 1973; Ofte et al. 1973; EPA 1974; Donnelly 1973), and evaluated by ChemRisk in Phase I of this project (ChemRisk 1994). At several times throughout Phase II, questions arose regarding the release of tritium to Walnut Creek, which drains into the GWR. The Walnut Creek drainage basins provides approximately 2% of the annual volume of the GWR water source (Ofte et al. 1973; Hurr 1976). This section briefly describes the tritium release event in 1973 and the special monitoring that ensued. Four tritium release incidents have been associated with the processing of tritium-contaminated scrap plutonium from Lawrence Livermore Laboratory (LLL):

- April 1969—57 Ci released
- March 1971—40 Ci released
- November 1971—29 Ci released
- April 1973—350–1600 Ci released to air; 50–100 released to the GWR.

In addition, about 1.5 Ci of tritium were released from exhaust system 205 in Building 777 in September 1974 due to a tritium contaminated sample container, which had been received from Battelle on July 17, 1974 (AEC 1974).The incident of most concern to the public was the April 1973 incident that released tritium to Walnut Creek which feeds into the GWR. This note briefly reviews and summarizes some of the key points of this release event, and presents some of the offsite monitoring results collected in the months following that event.

Background Information on Tritium

Tritium reaches surface water directly through precipitation, molecular exchange with water in the atmosphere, or direct releases of tritiated water, for example, from the Rocky Flats to Walnut and Woman Creek. Large quantities of tritium that completely overshadowed naturally produced tritium were released by the weapons testing before the natural distribution could be completely determined (NCRP 1979). It is estimated that the natural tritium inventory from cosmic ray interactions within the upper atmosphere is 35 megacuries (MCi) in each hemisphere. This activity is much lower than the 1900 MCi added to the Northern hemisphere by nuclear testing through 1963. The tritium inventory due to weapons testing reached a maximum of about 3100 MCi in 1963, an amount that will decay to the natural level of 70 MCi approximately by the year 2030 (NCRP 1979).

The kinetics of tritium movement throughout the human body follow those of water. A small fraction of the intake becomes organically bound in two separate compartments. The effective half-life of tritium in free water is 9.7 days compared to 30 days and 450 days from the two compartments into which the fraction is bound (NCRP 1979).

The 1973 Tritium Release Event

Approximately 500–2000 curies of tritium were transferred to Rocky Flats from the Lawrence Livermore Laboratory (LLL) in California in a shipment of waste materials that reached Rocky Flats on March 19, 1973. The incoming material consisted of scrap plutonium metal contaminated with tritium. It was packaged in four 30-gallon (114-liter) shipping containers. These were checked for alpha contamination, but not for tritium. The processing

operations were done from April 9–25, 1973 in Room 154 of Building 779A. These processes converted the plutonium metal to plutonium hydride, and then to plutonium oxide. The completely oxidized plutonium oxide was subsequently transferred to Building 771 for processing to reusable plutonium metal. Much of the tritium was released through the building stacks in airborne effluents. The remaining tritium followed the normal liquid waste processing flow, resulting in movement through Buildings 779, 771, 881, 444 and some other areas that handled the scrap. The treated liquid wastes from these buildings were discharged to the sanitary sewer or to the evaporation ponds over time. It was estimated that about 100–300 curies accumulated in the solar evaporation ponds, and 50–100 curies accumulated in the GWR (Ofte et al. 1973). Furthermore, analysis of water samples from the landfill area indicated that tritium was present in the landfill at least as early as May 1973 (Dow 1973).

Tritium Monitoring of Liquid Effluents

The CDH began its own monitoring program for tritium and other radionuclides and nonradioactive constituents following the May 1969 fire. They analyzed water for tritium from Walnut Creek at Indiana Street, Standley Lake, and the GWR, and occasionally from Woman Creek at Indiana. Figure 18a demonstrates the dramatic change in tritium levels in water from Walnut Creek at Indiana Street during April 1973. The tritium concentration was fairly constant at about 1000 pCi L^{-1}, with no significant increases in tritium concentrations in Walnut Creek at Indiana Street until April 24, 1973.

Following the large increase in tritium levels in April 1973, the tritium concentrations at that location decreased rapidly and returned to background levels by 1976 (Hurr 1976). The increase in tritium concentration was also evident in water from the GWR, although the peak tritium concentrations were much lower than those seen in Walnut Creek at the site boundary. Figure 18b shows the results of routine weekly monitoring of tritium in water from the GWR that had gone through the water treatment plant. The peak levels of tritium in the GWR were about 23,000 pCi L^{-1} measured in early June 1973. Table A-10 in Appendix A contains the weekly measurement values for tritium in the GWR.

In March 1972, Dow also began analyzing water samples for tritium to provide a cross-check of the CDH analyses at Walnut Creek and Indiana Street. It stopped the program after five months. Samples were cross-checked by the LLL and EPA during the investigation of the 1973 tritium release incident. Values ranged from about 800 to 10,000 pCi L^{-1}, with most values around 1000 pCi L^{-1} in 1972. During and following the tritium release beginning in April 1973, tritium levels rose to a maximum of 3,000,000 pCi L^{-1} on May 23, 1973. The tritium concentration slowly decreased during the next several months.

Tritium concentrations did increase in water from the GWR but not to the extent seen in water from Walnut Creek at Indiana Street. The tritium concentration increased over 100 times in water from Walnut Creek at Indiana Street. Smaller increases were seen in treated water from the GWR. There was no measurable difference in tritium concentrations in Standley Lake water before and after the tritium event. This observation is understandable since the plutonium processing areas discharge liquid effluent to the Walnut Creek drainage. Standley Lake receives effluents from Woman Creek.

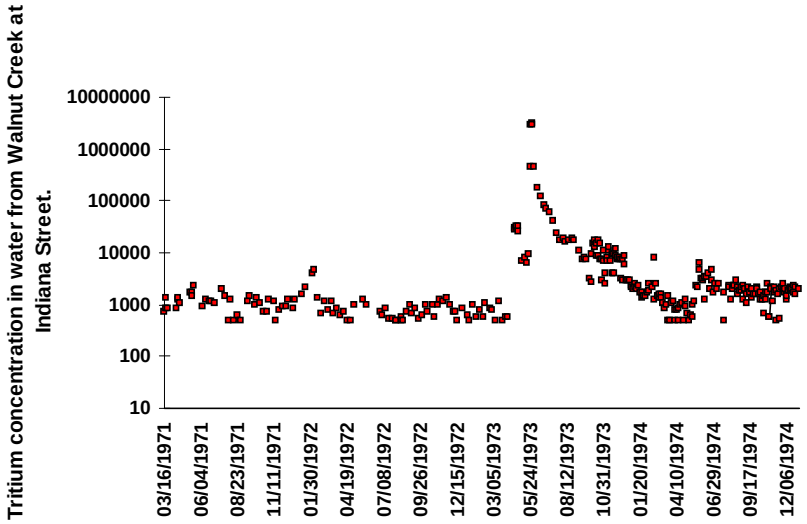

Figure 18a. Results of weekly monitoring of water from Walnut Creek at Indiana Street from March 1971 through December 1974.

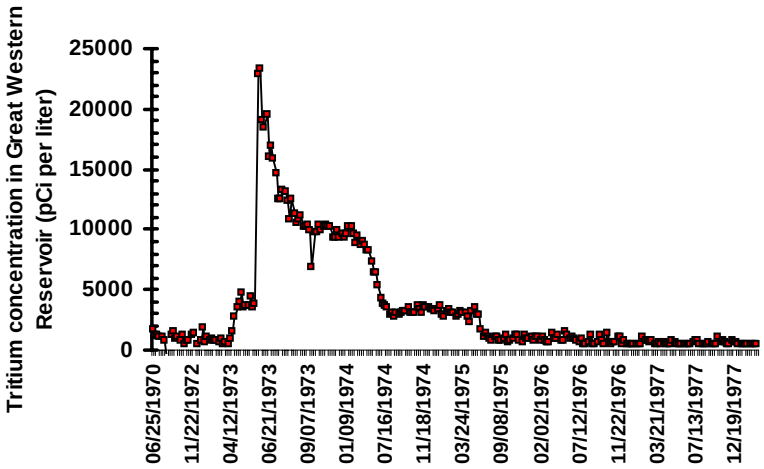

Figure 18b. Results of weekly monitoring of water from the Great Western Reservoir from June 1970 through December 1977.

Figure 18. Results of the routine weekly monitoring of water from Walnut Creek at Indiana Street (Figure 18a) and from the Great Western Reservoir (Figure 18b) by the Colorado Department of Health during the 1970s. CDH collected weekly samples beginning in June 1970. During and following the tritium release beginning in April 1973, tritium levels rose to a maximum of about 3,000,000 pCi L^{-1} on May 23, 1973 in water from Walnut Creek at Indiana Street (Figure 18a). The peak concentration of tritium in water from the GWR occurred about a week later but the peak tritium concentration in the reservoir (23,000 pCi L^{-1}) was over 100 times lower than the peak concentration measured in water at the site boundary (Figure 18b). The background tritium concentrations in surface water from distant locations ranged from approximately 800–1200 pCi L^{-1} during this time period.

Urine Analysis in Broomfield Residents

CDH collected urine from 36 non-occupationally exposed Broomfield residents, 17 males (15 over age 20, 2 under age 20) and 19 females (13 over age 20, 6 under age 20). The residents were separated into categories based on their use of the water supply:

- Lived and worked in an area serviced by GWR water supply
- Worked in an area serviced by GWR but lived elsewhere
- Lived in an area serviced by GWR but worked elsewhere.

The overall average tritium concentration for all ages was 4300 pCi L^{-1} with a standard deviation of 1200, compared to 610 pCi L^{-1} for the 12 control individuals (those not using the Broomfield water system). The geometric mean for all groups was 4100 pCi L^{-1} with a GSD of 1.36, compared to the controls with a GM of 560 pCi L^{-1} and a GSD of 1.59. The tritium concentrations in urine ranged from a high of 8100 pCi L^{-1} to a low of 1500 pCi L^{-1}. The minimum detectable activity for the method is 500 pCi L^{-1}. Figure 19 shows the results of the sampling program by age and sex. For perspective, the tritium concentration in urine of children from nine U.S. locations ranged from about 400 to 1500 pCi L^{-1} (Moghissi and Lieberman 1970).

Because tritium levels in the GWR had decreased from the high values measured in 1973 to background levels in 1976, CDH repeated the urine bioassay study of the Broomfield residents at that time. Figure 20, which compares the 1973 and 1976 results, indicates a significant decrease in the tritium concentration in urine of the Broomfield residents in 1976.

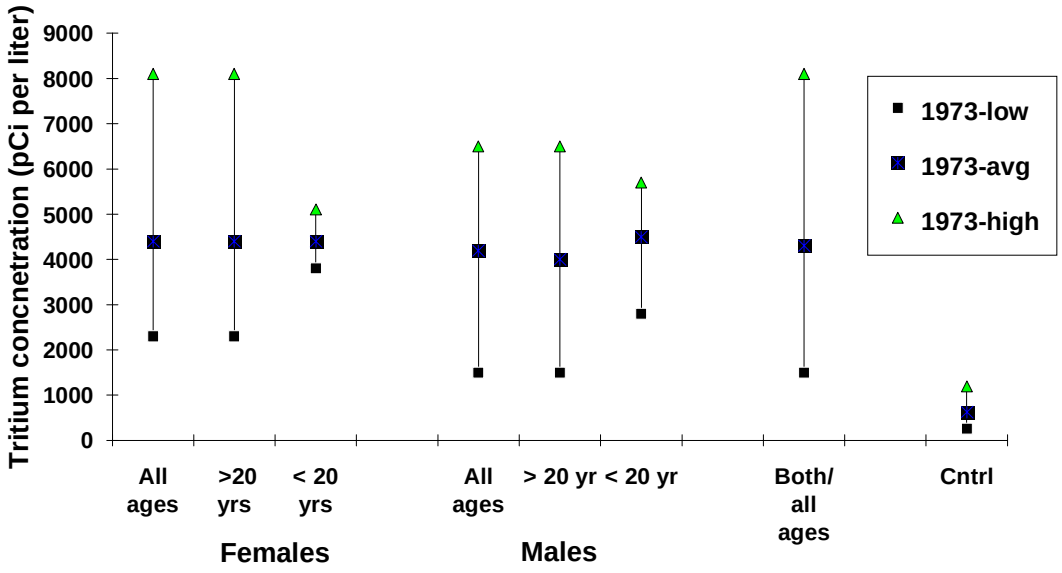

Figure 19. Summary of the tritium concentrations measured in the urine of non-occupationally exposed Broomfield residents in 1973 following an accidental tritium release at the Rocky Flats Plant into Walnut Creek. The creek drains into the Great Western Reservoir, which serves as the water supply of the City of Broomfield. The Walnut Creek drainage basin provided about 2% of the annual volume of the GWR water source at that time. "Cntrl" refers to results from a control group of 12 people living in the area but not using the Broomfield water system.

Estimated Dose from Tritium in Broomfield Drinking Water

This tritium release was previously considered by ChemRisk during Phase I of this project. ChemRisk, supported by the HAP, did not identify tritium as one of the materials of concern for further consideration in Phase II. As part of the Phase II work, *RAC* has briefly reviewed this incident because of questions raised by some members of the public. The measured tritium concentrations in the GWR following the tritium release event was used as the basis for estimating the radiation dose from ingestion of Broomfield water during the period of higher-than-normal tritium concentrations (Figure 18b). The basic formula for intake from the ingestion of tritium in drinking water is:

$$I\,(wtr) = C_{wtr}(U_{wtr})f_c(T_e) \qquad (1)$$

where

I = weekly intake of tritium due to water ingestion (pCi wk^{-1})

C_{wtr} = average concentration of tritium in water (pCi L^{-1})

U_{wtr} = average weekly consumption of drinking water (liter wk^{-1})

f_c = fraction of water consumed that is contaminated (dimensionless, 1.0)

T_e = exposure duration (1 week).

The time-integrated water concentration is computed by summing the concentration for each time increment (weekly) over the entire interval of higher-than-normal tritium concentrations. For this calculation, that time interval was from April 1973 through February 1976 (Figure 18b). By early 1976, the tritium concentration had returned to background levels measured in the GWR prior to the tritium release.

The committed effective dose equivalent is then determined with the equation:

$$D = I_{wtr}\,(DCF_T) \qquad (2)$$

where

D = committed radiation dose equivalent due to ingestion of excess tritium in drinking water from 1973 release (Sv pCi y^{-1})

DCF_T = dose conversion factor for ingestion of tritium, 1.73×10^{-11} Sv Bq^{-1} (0.0629 mrem μCi^{-1})

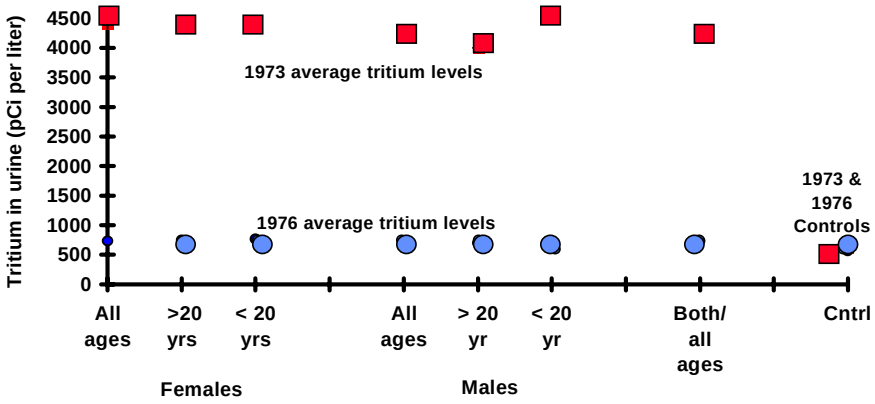

Figure 20. Comparison of tritium concentrations in the urine of non-occupationally exposed Broomfield residents in 1973 and 1976. The samples in 1973 were collected after an accidental tritium releases at the Rocky Flats Plant into Walnut Creek, which drains into the Great Western Reservoir, which serves as the water supply of the City of Broomfield.

The dose estimate incorporated sources of uncertainty and variability in the above parameters using Monte Carlo techniques in the Crystal Ball® program (Decisioneering 1993). Based on these calculations, the median estimate of the radiation dose from ingestion of Broomfield water during the period of high tritium concentrations is 0.32 mrem, with the 5th and 95th percentiles of 0.16 and 0.58 respectively. Table 14 provides information on doses from natural and fallout sources of tritium.

The estimated tritium concentration in the body water of humans is 400 Bq m^{-3} (12 pCi L^{-1}). The corresponding dose equivalent rate in tissue is 0.012 µSv y^{-1} (0.0012 mrem y^{-1}) (NCRP 1979). A tritium concentration in drinking water of about 20,000 pCi L^{-1} would contribute about 4 mrem to the person's dose for that year assuming that this was the sole water source for the entire year (Zillich 1974).

Table 14. Committed Dose Equivalent from Tritium in the Environment [a]

Source	Dose (mrem y^{-1})
Natural	0.0012
Fallout (1963)	0.2
Fallout (1980)	0.005
1973 tritium release from RFP (ingestion)	0.32 [b]

[a] From NCRP 1987
[b] 50-yr. committed dose

Uranium-Specific Measurements

While routine liquid effluent monitoring for alpha activity began in July 1953, measurements of uranium in the holding ponds and streams did not begin until 1971. By 1974, water was

sampled continuously and collected daily from the outfalls of the final ponds A-4 (on North Walnut Creek) , B-5 (on South Walnut Creek), and C-2 (on Woman Creek) before discharge to the site streams. Plutonium and uranium were isolated from other long-loved alpha emitters by ion exchange chromatography and their concentrations determined by alpha pulse-height spectrometry. Uranium recovery was determined by ^{232}U tracers (Dow 1974). Figure 21 shows that the highest annual concentrations were measured in the A and B series ponds on Walnut Creek, which drained into the GWR. The C ponds on Woman Creek, which drained into Standley Lake, had the lowest concentrations of uranium during this period. The values ranged from 2–11 pCi L^{-1} in the A ponds, 1–7 pCi L^{-1} in the B ponds, and 0.5–5 pCi L^{-1} in the C ponds. The highest annual average uranium levels in any ponds were measured in Pond A-4 in 1987 (11 pCi L^{-1}) and 1975 (9 pCi L^{-1}).

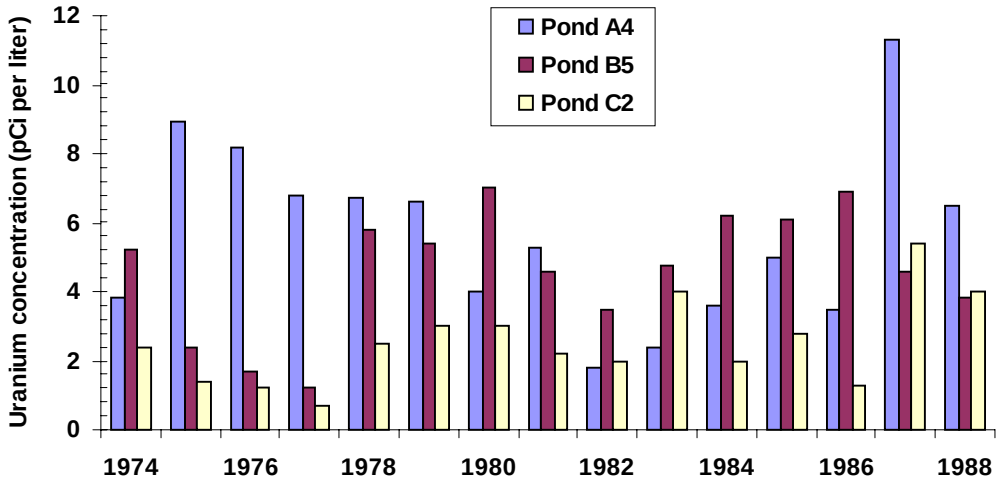

Figure 21. Annual average uranium concentrations measured in the final holding ponds (A-4, B-5, and C-2) before discharge to the site streams. Ponds A-4 and B-5 discharged into Walnut Creek and Pond C-2 discharged into Woman Creek. The background uranium levels measured in surface waters in other parts of Colorado ranged from about 2–8 pCi L^{-1} during this time period.

During this same time, water from Walnut Creek at Indiana Street (the buffer zone boundary) was sampled continuously and samples were composited weekly and analyzed for plutonium, uranium, and americium. Figure 22 shows the annual average uranium concentrations and peak uranium values measured form 1971 through 1988 as Walnut Creek left the Rocky Flats boundary. The annual average uranium values ranged from about 1 pCi L^{-1} in 1977 to about 9 pCi L^{-1} in 1971. The highest maximum uranium values measured during this 18 year period were seen in1974 (19 pCi L^{-1}) and 1978 (18 pCi L^{-1}).

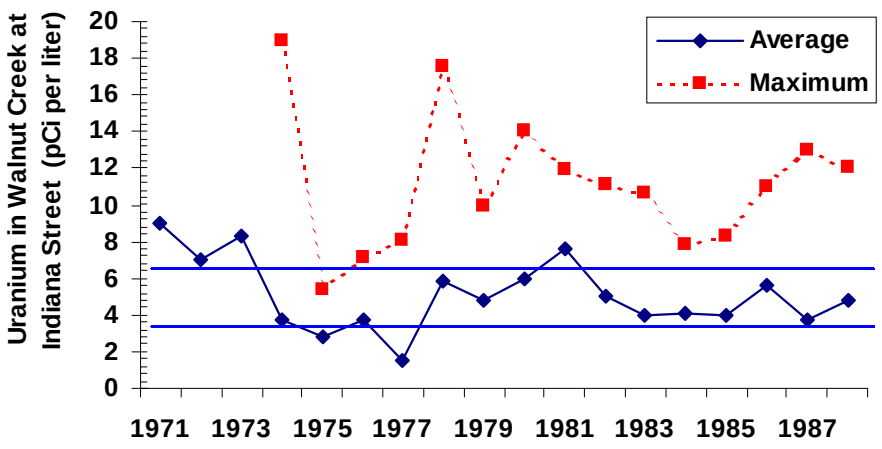

Figure 22. Annual average and maximum values of uranium measured in water from Walnut Creek at Indiana Street. The dashed lines show the approximate background levels of uranium in surface waters in Colorado (3–7 pCi L^{-1}). The regulatory standard for uranium in drinking water from 1971 through 1980 was 10,000 pCi L^{-1} (AEC 1968; ERDA 1974). In 1981 the uranium in drinking water standard was decreased to 200 pCi L^{-1} (DOE 1981).

More recently, researchers at the Los Alamos National laboratory (LANL) used Thermal Ionization Mass Spectrometry (TIMS) measurement techniques to characterize the uranium in the holding ponds at the RFP (Efurd et al. 1994). They concluded that all of the uranium in water samples collected from Pond A-1 and A-2 originated as depleted uranium. All other ponds, except C-1, contained measurable quantities of depleted uranium along with naturally occurring uranium. Furthermore, there was no enriched ^{235}U measured in any water samples collected from the ponds. It was noted that the uranium concentrations in water samples from the final holding ponds (A-4, B-5, and C-2) were 0.5% or less of the interim standard Derived Concentration Guide for uranium in waters available to the public.

CONCLUSIONS

Understanding onsite liquid effluent handling, processing and control, especially in the early years, has been important in determining whether rigorous reconstruction of plutonium releases to surface water from the RFP could be accomplished. There were procedures in place for the routine transfer of liquids to the waste processing areas, but only a limited amount of documentation has been identified to verify how well the procedures were carried out. While extensive data were located for releases to South Walnut Creek via the B holding ponds, data on releases to North Walnut Creek via the A ponds and to Woman Creek were more limited.

Routine liquid effluent monitoring began July 1953, and *RAC* located original handwritten logbooks for some years, and monthly reports for most years to help in the documentation of releases to North and South Walnut Creeks and Woman Creek. Most of the values, however, do

not include estimates from unmonitored runoff from contaminated ground surfaces. The collection of water samples changed from grab sampling and estimating effluent volumes in 1953 to the use of a crude continuous sampler by August 1955. Until 1972, samples were transported to the laboratory where they were acidified, filtered, and evaporated. The quality of the water monitoring data was affected by factors such as the presence of sediment in collected samples, extraneous activity introduced in the analysis process and the analytical method itself.

The gross alpha measurements in liquid effluents released from the site before 1970 correspond fairly well to release events onsite, and the data are useful for supporting the relative magnitude of routine releases. Evaluating data on a monthly rather than an annual basis aided in understanding the site operations and how liquid effluents were processed. In this current report, a method was used to estimate plutonium releases for earlier years when only gross alpha was measured. This was done by calculating a ratio of monthly plutonium to alpha activity for three years when both measurements were made, and applying it to measurements of alpha activity released from the same location from 1952 to 1969 (when plutonium was not measured).

This method provides one approach for bounding the plutonium releases to South Walnut Creek from the B ponds in the early years. Based on this ratio method, the total plutonium released from the B ponds to South Walnut Creek through 1969 was estimated to be 20 mCi (90% confidence interval of 6 to 55 mCi). There are limitations to this method, and it is not easily applicable to estimating releases of plutonium to Woman Creek because the historic record of measurements is not as complete. However, these studies are important because they may help us to better understand the plutonium inventory in sediment in the GWR. Various sediment studies have shown that the majority of the plutonium inventory in the GWR is from liquid releases from the RFP. Studies by CSU have provided plutonium inventory estimates in the GWR of 50 to 80 mCi.

More recent studies and projects at the RFP have been designed to improve the effluent handling and waste processing. For example, the RFP Surface Water Control System was completed in 1980. It was designed as a means of improving the water retention capability of the site in the event that surface runoff water from the site proved “unsuitable for discharge” (Henry 1986). The system consisted of three earth-filled dams—Pond A-4 (95 acre-feet), Pond B-5 (73 acre-feet), and Pond C-2 (69 acre-feet) — and one concrete and one rockfill diversion dam that intercepts surface runoff from the west side of the plant and delivers it to the McKay Ditch bypass canal [2 mi (2 km) of canal north of the site]. Another concrete and rockfill diversion dam intercepts surface water from Woman Creek and diverts it around Pond C-2. The south Interceptor Canal [2 mi (3.2 km) of canal south of the site] that diverts surface runoff from the southern portion of the Site to Pond C-2.

These modifications resulted in a general decrease in the number and extent of offsite releases to surface water (EG&G 1993a). A statistical analyses of plutonium, americium, uranium, total alpha, and beta levels measured in water from Ponds C-1, C-2, B-5, A-4, Walnut Creek, and the reservoirs from December 1987 to August 1990 supported this observation (Bauer and Weier 1991).

REFERENCES

AEC (Atomic Energy Commission). 1968. *Standards for Radiation Protection*. U.S. Atomic Energy Commission, AEC Manual, Chapter 0524. AECMC-0524. U.S. Atomic Energy Commission, Washington, D.C.

AEC (Atomic Energy Commission). 1974. *Investigation of a Tritium Release Occurring in Building 777 on September 3-4, 1974 at USAEC's Rocky Flats Plant Golden, Colorado.* U.S. Atomic Energy Commission, Washington, D.C.

Allen, I.B., D.C. Coonfield, R.R. Gunning, F.D. Hobbs, C.T. Illsley and J.M. West. 1974. *Annual Environmental Monitoring Report Rocky Flats Plant January through December 1973.* RFP-ENV-73. Dow Chemical Company, Golden, Colorado. April 26.

Barker, C.J., R.B. Falk, R.L. Henry, C.T. Illsley, N.D. Kirk, I.M. Meisel, R.V. Reischick, L.F. Smith, J.M. West and T.F. Winsor. 1981. *Annual Environmental Monitoring Report Rocky Flats Plant January through December 1980.* RFP-ENV-80. Rockwell International, Golden Colorado. April 20.

Bauer, J.F. and D.R. Weier. 1991. *Pond Water Analysis Summary*. RFP-4500. Statistical Applications. 12/87 to 8/90. January 21.

Blaha, F. 1987. Ground Water Monitoring Past and Present at Rocky Flats. NT-RP-00047. Rockwell International, Denver, Colorado. December 4.

Bokowski, D.L. 1974. Liquid scintillation counting for plutonium in environmental samples. RFP 2037. Dow Chemical Company, Golden, Colorado. June.

Bokowski, D.L., R.L. Henry and D.C. Hunt. 1981. *History and Evaluation of Regional Radionuclide Water Monitoring and Analysis at the Rocky Flats Installation*. RFP-3019, DOE/TIC-4500. Rockwell International, Denver, Colorado.

Boss, M.R., F.D. Hobbs, R.W. Loser and D.E. Michels. 1973. *Annual Environmental Monitoring Report Rocky Flats Plant January through December 1972*. RFP-ENV-72. Golden, Colorado: Dow Chemical USA. April 13.

CDH (Colorado Department of Health). 1970-1978. Rocky Flats Plant monthly numerical summary of data pertaining to environmental surveillance.

CDH. 1971. *Water Quality Standards and Stream Clarification.* Water Pollution Control Commission, Colorado Department of Public Health, Denver, Colorado.

CDH. 1977. *Primary Drinking Water Regulations Handbook.* State of Colorado, Water Quality Control Division, Colorado Department of Health. December 15.

ChemRisk. 1992. *Reconstruction of Historical Rocky Flats Operations & Identification of Release Points. Final Draft Report For Tasks 3 & 4 For Phase I.* ChemRisk, Alameda, California. August.

ChemRisk. 1994. *Estimating Historical Emissions From Rocky Flats. Project Task 5 Report For Phase I.* ChemRisk, Alameda, California. March.

Clow, D.W. and D. A. Johncox. 1995. *Characterization of Selected Radionuclides in Sediment and Surface Water in Standley Lake, Great Western Reservoir, and Mower Reservoir, Jefferson County, Colorado, 1992.* Water-Resources Investigation Report 95-4126. Denver, Colorado. U.S. Geological Survey.

Decisioneering. 1993. Crystal Ball® Version 3.0 for Windows. *User's Manual*. Decisioneering, Inc., Denver, Colorado.

DOE (U.S. Department of Energy). 1980. *Final Environmental Impact Statement, Rocky Flats Plant Site, Golden, Colorado*. Rep. DOE/EIS-0064. National Technical Information Service, Springfield, Virginia.

DOE. 1981. *Standards for Radiation Protection*. DOE Order 5480.1, Change 6, Chapter XI, Department of Energy, Washington, DC. August 13.

DOE. 1991. *Final Past Remedy Report. Operable Unit No. 3-IHSS 199*. Environmental Restoration Program. Rocky Flats Plant, Golden, Colorado.

Donnelly, H.C. 1973. "Report of investigation of tritium contamination detected in Rocky Flats environs." Letter to M.B. Biles, Division of Operational Safety AEC, accompanying draft report of investigating committee of September 20, 1973.

Dow (Dow Chemical Company). 1952–1953. Environmental analysis logbooks for water and vegetation monitoring. EMF 22840. Dow Chemical Company, Golden, Colorado.

Dow. 1960. Environmental Survey for January through March 1960, April–June 1960. Dow Chemical Company, Golden, Colorado.

Dow. 1961. Environmental Survey for October through December 1960. Dow Chemical Company, Golden, Colorado. January 30.

Dow. 1969. Rocky Flats Climatography–Year 1969 Environmental Master File #3845. Dow Chemical Company, Golden, Colorado, January 30.

Dow. 1970. Environmental Survey for January–June, 1970. Dow Chemical Company, Golden, Colorado. January 30.

Dow. 1969–1972. Daily handwritten logbooks of liquid effluents received at the sanitary treatment facility. Dow Chemical Company, Golden, Colorado.

Dow. 1973. *Draft Report to the Committee Investigating the Rocky Flats Tritium Release Investigation of a Tritium Release Occurring in Building 777 on September 3-4, 1973*. Dow Chemical Company, Golden, Colorado.

Dow. 1974. *Annual Environmental Monitoring Report Rocky Flats Plant January through December 1973*. RFP-ENV-73. Dow Chemical Company, Golden Colorado. April 26.

Dow. 1974–1979. Environmental analysis logbooks for water and vegetation monitoring. Environmental Master File document number 22840, Dow Chemical Company, Golden, Colorado.

Dow. 1975. *Annual Environmental Monitoring Report Rocky Flats Plant January through December 1974*. RFP-ENV-74. Dow Chemical Company, Golden Colorado. April 29.

Efurd, D.W., D.J. Rokop, R.D. Aguilar, F.R. Roensch, J.C. Banar, and R.E. Perrin. 1994. *Identification and Quantification of Source-Terms for Uranium in Surface-Waters Collected at the Rocky Flats Facility*. LA-UR-94-3924. Los Alamos National Laboratory, Los Alamos, New Mexico.

EG&G. 1990. Environmental Analysis Report, Rocky Flats Plant Site. Draft. U.S. Department of Energy, Rocky Flats Plant, Golden, Colorado. February 28.

EG&G. 1991. *Surface Water and Sediment Geochemical Characterization Report. Environmental Restoration Program*. EG&G Rocky Flats, Golden, Colorado. February 22.

EG&G. 1993a. *Rocky Flats Plant Site Environmental Report for 1992*. RFP-ENV-92. EG&G Rocky Flats, Golden, Colorado. April 29.

EG&G. 1993b. *Event-Related Surface-Water Monitoring Report. Rocky Flats Plant: Water Years 1991 and 1992*. EG&G Rocky Flats, Colorado. November.

EG&G. 1994. *Groundwater Protection and Monitoring Program Plan, Draft Final.* EG&G Rocky Flats, Inc., Golden, Colorado. September.

Ellerbrock, J. 1982. Rocky Flats Early Monitoring Data (May 1952–June 1972) Broomfield Municipal and Great Western Reservoir. University of Colorado, Boulder, Colorado.

EPA. 1974. *Investigative Report of the 1973 Tritium Release at the Rocky Flats Plant in Golden, Colorado.* U.S. Environmental Protection Agency. July.

EPA. 1976. *Drinking Water Regulations, Radionuclides*. Federal Register 41 (133): 28402-28409. July 9.

ERDA (Energy Research and Development Administration). 1974. *Effluent and Environmental Monitoring and Reporting*. ERDA Manual, Chapter 0513. U.S. Energy Research and Development Administration, Washington, D.C.

Farrell, L.C. 1955. Justification for two water tight evaporation ponds for liquid wastes. Memorandum to B.F. Shepherd dated May 27, 1955. Dow Chemical Company, Golden, Colorado.

Farrell, L.C. and E.S. Ryan. 1957. Revisions to Portion of Unclassified Document NYO 7830 Pertaining to Rocky Flats Plant Waste Disposal Operations Based on Fiscal Year 1957 data. EG&G 1600637, pp 127, 130, 131, 133, 134, 136, and 137. Dow Chemical Company, Golden, Colorado.

Grogan, H. A., K. R. Meyer, P. G. Voillequé, S. K. Rope, M. J. Case, H. R. Meyer, R. E. Moore, T.F. Winsor and J. E. Till. 1994. Task 2: Verify Phase I Source Term and Uncertainty Estimates. The Rocky Flats Nuclear Weapons Plant Dose Reconstruction Project. Phase II: Toxicity Assessment and Risk Characterization. RAC Report No. CDH-1. Radiological Assessments Corporation, Neeses, SC. July.

HAP (Health Advisory Panel). 1993. *Health Advisory Panel's Report to Colorado Citizens on the Phase I Study of the State of Colorado's Health Studies on Rocky Flats.* Colorado Department of Public Health and Environment, Rocky Flats Health Studies.

Henry, R.L. 1986. *Trends Observed in Rocky Flats Surface Water*. Rockwell International, Denver, Colorado.

Hoffman, N.D. 1982. *An Historical Evaluation of Radiological and Chemical Properties of Water From Hydrologic Test Wells at Rocky Flats*. EA-376-81-231. Rockwell International, Denver, Colorado.

Hoffman, N.D. 1984. *Nonradioactive Groundwater Data Summary 1975–1983*. C-R No. 331. Rockwell International, Denver, Colorado.

Hornbacher, D.D. and C.J. Barker. 1975. *Radioactive Effluent Monitoring at the Rocky-Flats-Plant*. RFP 02447. September 23, 1975. Rockwell International, Golden, Colorado.

Hurr, R. T. 1976. *Hydrology of a Nuclear-Processing Plant Site, Rocky Flats, Jefferson County., Colorado*. U.S. Geological Survey, Denver, Colorado. March.

Johnson, J.E., S. Svalberg, and D. Paine. 1974. *The Study of Plutonium in Aquatic Systems of the Rocky Flats Environs*. Colorado Department of Health, Fort Collins, Colorado.

Joshel, L.M. 1971. *Rocky Flats 1969 Environmental Survey Report*. Dow Chemical Company, Golden, Colorado. February 18.

Kittinger, W.D. and F.J. Linck. 1970. *Study for POSC Task Force - Status and Recommendations Concerning Building Air Effluents at Rocky Flats*. Letter to T.R. Barry, C.F. Bogard, S.E. Hammond, F.J. Linck, C.M. Love, L.A. Matheson and R.W. Woodard. Dow Chemical Company, Golden, Colorado. January 23.

Kaiser-Hill. 1994. Rocky Flats Environmental Technology Site Environmental Report. RFP-ENV-94. Kaiser-Hill Company, L.L.C. Golden, Colorado.

Love, C.M., T.R. Barry, C.F. Bogard, S.E. Hammond, D.S. Irwin, W.D. Kittinger, F.J. Linck, L.A. Matheson and R.W. Woodard. 1970. *Report of the Task Force on Potential Offsite Contamination.* Dow Chemical Company, Golden, Colorado. June.

McGavran, P.D. and A.S. Rood. 1999. *Estimated Exposure and Lifetime Cancer Incidence Risk from Carbon Tetrachloride Released to the Air from the Rocky Flats Plant.* RAC Report No. 4-CDPHE-RFP-1997-FINAL(Rev.1). *Radiological Assessments Corporation*, Neeses, South Carolina. August.

Moghissi, A.A. and R. Lieberman. 1970. "Tritium Body Burden of Children, 1967-1968." *Radiological Health Data and Reports* 11 (5): 227–236.

NCRP (National Council on Radiation Protection and Measurements). 1979. *Tritium in the Environment*. NCRP Report No. 62. Washington, D.C.

NCRP. 1987. *Exposure of the Population in the United States and Canada from Natural Background Radiation*. NCRP Report No. 94. Washington, D.C.

Ofte, D., F.E. Coffman, and D.R. Elle. 1973. Investigation of the Tritium Release Occurrence at the Rocky Flats Plant. AEC (Atomic Energy Commission). November 26.

Owen, J.B. and L.M. Steward. 1974. *A Historical Summation of Environmental Incidents Affecting Soils at or Near the US AEC Rocky Flats Plant*. Dow Chemical Company, Golden, Colorado.

Owen, J.B. 1974. *History of 207 Solar Evaporation Ponds and Nitrate in Walnut Creek*. Report to E.W. Bean, U.S. Atomic Energy Commission. Dow Chemical Company, Golden, Colorado. April 10.

PHS (Public Health Service). 1962. *Public Health Service Drinking Water Standards*. U.S. Department of Health, Education and Welfare, Washington, D.C.

Plock, C.E. 1972. *A Survey of the Rocky Flats Division Waste Streams*. C-R No. 1107. Dow Chemical Company, Golden, Colorado. June 30.

Rockwell. 1976. *Annual Environmental Monitoring Report Rocky Flats Plant January through December 1975*. RFP-ENV-75. Rockwell International, Golden, Colorado. May 17.

Rockwell. 1977. *Annual Environmental Monitoring Report Rocky Flats Plant January through December 1976*. RFP-ENV-76. Rockwell International, Golden, Colorado. May 6.

Rockwell. 1978. *Annual Environmental Monitoring Report Rocky Flats Plant January through December 1977*. RFP-ENV-77. Rockwell International, Golden, Colorado. May 8.

Rockwell. 1979. *Annual Environmental Monitoring Report Rocky Flats Plant January through December 1978*. RFP-ENV-78. Rockwell International, Golden, Colorado. May 15.

Rockwell. 1980. *Annual Environmental Monitoring Report Rocky Flats Plant January through December 1979*. RFP-ENV-79. Rockwell International, Golden, Colorado. April 10.

Rockwell. 1983. *Annual Environmental Monitoring Report Rocky Flats Plant January through December 1983*. RFP-ENV-83. Rockwell International, Golden, Colorado. April 15.

Rockwell. 1988. *Solar Evaporation Ponds Closure Plan*. Rockwell International, Golden, Colorado.

Rope, S.K., K.R. Meyer, M.J. Case, H.A. Grogan, D.W. Schmidt, M. Dreicer, T.F. Winsor, and J.E. Till. 1999. *Evaluation of Environmental Data for Historical Public Exposures Studies*

on Rocky Flats. RAC Report No. 1-CDPHE-RFP-1997-FINAL(Rev.1). *Radiological Assessments Corporation.* Neeses, South Carolina. August.

Ryan, E. S. 1953–1971. *Monthly Progress Reports-Waste Disposal*. Dow Chemical Company, Golden, Colorado.

Ryan, E.S. 1955. *Monthly History Reports—Waste Disposal Co-Ordination Group-January–December 1955*. Report to L. C. Farrell. Dow Chemical Company, Denver, Colorado.

Ryan, E. S. 1961. Meeting on Plant Waste Disposal Problems-December 29, 1960. Report to J. G. Epp. Dow Chemical Company, Denver, Colorado. 9 January.

Ryan, E. S. 1963. History Report-Process Waste Disposal Group-June 1963 and Summary for Fiscal Year 1963. Memo to G. E. White. July 30.

Ryan, E. S. 1964. History Report-Process Waste Disposal Group-June 1964 and Summary for Fiscal Year 1964. Report to G. E. White. July 29.

Ryan, E.S.; J.N. Vance, and M.E. Maas. 1965. *Aqueous Radioactive Waste Treatment Plant at Rocky Flats*. RFP-638. Dow Chemical Company, Golden, Colorado. October 25.

Schoep, D. A. and F.W. Whicker. 1995. "^{239,240}Pu and ^{137}Cs in the Sediment of Great Western Reservoir", In: *Plutonium and Americium in the Environs of Rocky Flats: Spatial Distribution, Environmental Transport, and Human Exposure - Preliminary Draft, A Report to Dow Chemical Company and the Colorado Department of Public Health*, F.W. Whicker and S.A. Ibrahim, Principal Investigators. Colorado State University, Fort Collins, Colorado.

Steward, L.M. and M.R. Boss. 1972. *Annual Report: Environmental Safeguard 1971 Radioactive Monitoring and Environmental Surveillance January through December 1971*. RFP-ENV-71B. Dow Chemical Company, Golden, Colorado. March 10.

Thackeray, R.S. 1953. Analysis of Site Survey Data. Special Problems Group. Dow Chemical Company, Denver, Colorado. July 2.

Thomas, C. W. 1975. *Draft Report on Studies of Great Western Reservoir and Standley Lake*. Report to M. Thompson. Battelle Pacific Northwest Laboratories, Richland, Washington. April 16.

Thomas, C. W. and D. E. Robertson. 1981. *Radionuclide Concentrations in Reservoirs, Streams and Domestic Waters Near the Rocky Flats Installation*. Pacific Northwest Laboratory, Richland, Washington. April.

Thompson, M.A. 1975. “Plutonium in the Aquatic Environment Around the Rocky Flats Facility". In *Impacts of Nuclear Releases into the Aquatic Environment*. IAEA-SM-198/38. International Atomic Energy Agency, Vienna.

Werkema, M.V. 1974. *Catalogue of Monitoring Activities at Rocky Flats*. RFP-2921. Environmental Sciences. Rockwell International, Golden, Colorado.

White, G.E. 1963. Evaporation Ponds. Memorandum to J.G. Epp. Dow Chemical Company, Denver, Colorado. July 26.

Zillich, J.A. 1974. Biological Impacts of Rocky-Flats Wastes Discharged to Surface Waters. RFP-2210. Rockwell International, Golden, Colorado. April 9.

APPENDIX A

TABLES RELATED TO SURFACE WATER RELEASES

Table A-1. Stream Flow in North Walnut Creek at Rocky Flats Plant (Station No. 06720780)[a]

Date	No. days with no flow	Max	Mean	Min	Total Volume cubic ft	Total Volume acre-ft
Jun-72	12	2	0.19	[b]	5.61	11
Jul-72	31		No flow			
Aug-72	18	1.5	0.16	[b]	5.05	10
Sep-72	10	0.98	0.15	[b]	4.41	8.7
Oct-72	22	0.05	0.009	[b]	0.27	0.5
Nov-72	18	0.17	0.031	[b]	0.92	1.8
Dec-72	4	0.11	0.047	[b]	1.46	2.9
Jan-73	0	0.3	0.21	0.05	6.4	13
Feb-73	0	0.3	0.27	0.2	7.65	15
Mar-73	0	1.9	0.66	0.17	20.49	41
Apr-73	0	8	3.9	0.87	116.87	232
May-73	0	21	2.84	0.01	88.11	175
Jun-73	3	0.14	0.03	b	0.91	1.8
Jul-73	6	0.21	0.019	b	0.59	1.2
Aug-73	31	no flow				
Sep-73	25	0.4	0.037	b	1.1	2.2
Oct-73	26	0.92	0.064	b	1.98	3.9
Nov-73	21	0.52	0.038	b	1.14	2.3
Dec-73	0	1.4	0.26	0.01	8.16	16
Jan-74	0	2.1	0.86	0.5	26.59	53
Feb-74	0	1.2	0.67	0.19	18.73	37
Mar-74	0	2.5	1.5	0.8	46.35	92
Mean		2.3	0.60	0.25	18	34
Median		0.95	0.18	0.18	5.3	10

[a] USGS gauging station at latitude 395357, longitude 1051103 (Hurr 1976).
[b] Minimum is no flow.

Table A-2. Water Flow in South Walnut Creek at Rocky Flats Plant (Station No. 06720790)[a]

				Total Volume	
Date	Max	Mean	Min	cubic ft	acre-ft
Jul-72	0.52	0.36	0.15	11.03	22
Aug-72	1.6	0.29	0.09	9.14	18
Sep-72	1	0.41	0.02	12.22	24
Oct-72	0.88	0.21		6.52	13
Nov-72	0.75	0.35	0.09	10.4	21
Dec-72	0.3	0.28	0.25	8.8	17
Jan-73	0.35	0.33	0.3	10.31	20
Feb-73	0.37	0.28	0.16	7.97	16
Mar-73	0.63	0.36	0.2	11.09	22
Apr-73	2.2	0.81	0.09	24.4	48
May-73	40	3.14	0.12	97.3	193
Jun-73	0.5	0.4	0.16	11.94	24
Jul-73	0.75	0.26	0.12	8.09	16
Aug-73	0.28	0.13	0.05	4.13	8.2
Sep-73	1	0.31	0.04	9.38	19
Oct-73	1	0.27	0.02	8.3	16
Nov-73	0.64	0.17	0.01	5.19	10
Dec-73	0.92	0.3	0.02	9.17	18
Jan-74	1.7	0.31	0.1	9.74	19
Feb-74	0.35	0.22	0.03	6.08	12
Mar-74	2	0.3	0.1	9.21	18
Apr-74	1.1	0.42	0.1	12.66	25
May-74	0.47	0.16	0.01	4.89	9.7
Jun-74	2.4	0.16	0.01	4.86	9.6
Jul-74	0.2	0.023	0.01	0.7	1.4
Aug-74	0.12	0.036	0.01	1.12	2.2
Sep-74	0.14	0.036	0.01	1.07	2.1
Oct-74	0.61	0.19	0.01	5.8	12
Mean	2.2	0.38	0.08	11.5	23
Median	0.70	0.29	0.08	9.0	18

[a] USGS gauging station at latitude 395414, longitude 1051103 (Hurr 1976).

Table A-3. Stream Flow in Woman Creek at the Rocky Flats Plant (Station No. 06720700)[a]

Date	No. days with no flow	Max	Mean	Min	Total Volume cubic ft	Total Volume acre-ft
Aug-72	3	0.19	0.037	0.01	1.13	2.2
Sep-72	0	0.98	0.17	0.03	5.2	10
Oct-72	0	0.61	0.18	0.02	5.7	11
Nov-72	0	0.78	0.49	0.34	14.57	29
Dec-72	0	0.61	0.42	0.12	13.08	26
Jan-73	0	0.98	0.61	0.15	18.76	37
Feb-73	0	1.7	0.91	0.54	25.35	50
Mar-73	0	2.6	1.09	0.54	33.8	67
Apr-73	0	50	17.2	1.5	516.6	1020
May-73	0	60	11.5	0.5	357.5	709
Jun-73	0					
Jul-73 [b]		0.49	0.17	0.03	5.24	10
Aug-73		0.38	0.13	0.04	4.10	8.1
Sep-73		0.47	0.12	0.04	3.74	7.4
Oct-73		0.28	0.09	0.05	2.74	5.4
Nov-73		0.36	0.22	0.13	6.49	13
Dec-73		0.52	0.28	0.19	8.82	17
Jan-74		2.00	0.50	0.20	15.45	31
Feb-74		0.67	0.43	0.26	12.14	24
Mar-74		1.20	0.37	0.22	11.58	23
Apr-74		3.8	0.9	0.19	26.87	53
May-74		2	0.75	0.41	23.1	46
Jun-74		2.5	0.44	0.14	13.27	26
Jul-74		0.48	0.29	0.12	9.03	18
Aug-74		0.4	0.3	0.19	9.24	18
Sep-74		0.64	0.3	0.15	8.96	18
Oct-74		0.73	0.31	0.14	9.63	19
Mean		5.0	1.4	0.24	43	88
Median		0.67	0.36	0.15	9.6	21

[a] USGS gauging station at latitude 395308, longitude 1051105 (Hurr 1976).

Table A-4. Rocky Flats Plant Holding Tank Descriptions [a]

Building	No. of Tanks	Capacity (gal)	Construction
123	1	8,700	Concrete
444	2	3,500 each	Welded Steel
559	2	2,000 each	Stainless Steel
	1	600	Stainless Steel
707	2	3,000 each	Concrete
771	2	14,000 each	Concrete
776/777	2	22,500 each	Concrete
	2	4,500 each	Concrete
779	2	1,000 each	Concrete
	2	8,000 each	Concrete
865	2	3,000 each	
881	4	250 each	Welded Stainless Steel
	7	3,000 each	Welded Stainless Steel
883	4	1,000 each	Welded Steel
	1	750	Welded Steel
889	2	1,000 each	Concrete with Carboline Lining
Ponds			
207A	-	6,155,000	Asphalt-planked
207B N	-	2,429,000	Asphalt-planked
207B C	-	2,310,000	Asphalt-planked
207B S	-	2,188,000	Asphalt-planked
207C	-	1,673,000	Asphalt-planked

[a] Adapted from Ofte et al. 1973.

Table A-5. Rocky Flats Plant Waste Treatment Tankage [a]

Tank No.	Capacity (gal)	Material	Function
2-F	100	Stainless Steel	Receiving Tank--771 Ion Column Effluent
Part V	100	Stainless Steel	Receiving Tank--771 Part V
4-L	1,400	Stainless Steel	Receiving Tank--771 Distillate and Am Ion Column Effluent
4-R	1,400	Stainless Steel	Receiving Tank--771 Incinerator Caustic Scrub
1-A	2,000	Stainless Steel	Receiving and Feed Tank--771 Wastes
1RF	2,000	Stainless Steel	Receiving and Feed Tank--771 Wastes
12	1,000	Stainless Steel	Neutralizer Tank--771 Part V and Ion Column Effluent
9	300	Stainless Steel	Slurry Tank, Filter Feed--771 Wastes
10	500	Stainless Steel	Slurry Tank, Filter Feed--771 Wastes
Clarified	750	Stainless Steel	Clarifier--771 Wastes
Flocculator	1,500	Stainless Steel	Flocculator--771 Wastes
Flash Mixer	50	Stainless Steel	Flash Mixer--771 Wastes
11-R	750	MS-Rubber Lined	Sand Filter--771 Wastes
11-L	750	MS-Rubber Lined	Sand Filter--771 Wastes
66	14,000	Concrete	High Nitrate Storage and Treatment--All Wastes
67	14,000	Concrete	High Nitrate Storage--All Wastes
68	30,000	Concrete	High Nitrate Treated Waste Storage--All Wastes
207	200,000	Mild Steel	Low Nitrate Waste Storage--Primarily Laundry Waste
2-Stage Flocculator	15,000	Stainless Steel	Flocculator--Low Nitrate Wastes Primarily Laundry Waste
40	7,200	Concrete	Slurry Holding Tank--All Wastes
37	2,00	Stainless Steel	Slurry Holding Tank--All Wastes
TT 201	15,000	Stainless Steel	Low Nitrate Treated Waste Storage
102	10,000	Mild Steel	Evaporator Feed Tank--Pond 207A
103	10,000	Mild Steel	Evaporator Feed Tank--Pond 207A

[a] Adapted from Ofte et al. 1973.

Table A-6. Characteristics of the Solar Evaporation Ponds [a]

Ponds	Date in service	Area (acres)	Max. depth	Dates of Modifications
207A	Aug 1956	3	7.5	Nov 1963 (asphalt concrete); 1984 (equipment installed to clean out pond).
207B North	June 1960	1	6.5	Aug 1961(asphalt concrete); Apr 1967(filled cracks with mastic); Nov 1967(repaired sidewalls with burlap & asphalt covering); Oct 1968(additional coat of asphalt); Nov 1969 (covered all side walls with burlap and asphalt); Oct 1971 & Sep 1973 (covered side walls with petromat and hydraulic sealant); July 1977-(decommissioned).
207B Central	June 1960	1	6.5	Aug 1961 (asphalt concrete); Apr 1967(filled cracks with mastic); Nov 1967(repaired sidewalls with burlap & asphalt covering); Oct 1968, Oct 1969 (repaired cracked side walls with burlap and asphalt); Oct 1971 (covered side walls with petromat and hydraulic sealant); July 1977-(decommissioned).
207B South	June 1960	1	5.5	Nov 1960 (asphalt concrete); Apr 1967(filled cracks with mastic); Sep 1970 (Covered all side walls with burlap and asphalt); July 1977-(decommissioned).
207C	Dec 1970	1	7	

[a] From Farrell 1955, White 1963; Owen 1974; DOE 1980; Rockwell 1988.

Table A-7. Highlights of Early Effluent Monitoring History at the RFP

- Waste Disposal Unit organized in January 1953 under J. Epp and F. Langell to supervise the "ultimate disposal of processed liquid and solid wastes and the correlations of the allied data." E.S. Ryan was the chemist in charge of correlating the data. The group issued monthly progress reports.
- In 1953, site analyzed effluent for total solids, pH, nitrates. Water Laboratory of the General Laboratory conducted the analyses. A major effort was to remove or reduce nitrate content of liquid waste.
- Construction of ponds to the east of Building 95 was reported in June 1953. In August 1953, liquid wastes from Building 23 went directly to the sanitary system instead of to the Building 741 reservoir.
- In July 1953, sampling of retention ponds began; the number of discharges, volume, total activity, average concentration were reported.
- In September 1953, inlet and outlet of the B lower retention pond were sampled daily for pH and nitrates.
- In October 1953, the Waste Disposal Unit progress report also began reporting the quantities of solid wastes in storage.
- In February 1954, there was a disruption in Building 95 (sewage treatment plant) due to release of steam condensate from Building 81. The waste contained chromate and at high enough temperatures to raise the temperature of the influent to Building 95 "several degrees".
- On March 10, 1954, water was first released from the A-pond on North Walnut Creek. Weekly samples were taken from the effluent.
- Four retention ponds on Woman Creek were completed; first discharge from the large pond occurred on March 29, 1955.
- In August 1955, a crude continuous sampler was installed at the outlet of Pond B-3 (5); it collected a 50 gallon (190 liter) sample over a 24-hr period.
- By 1963, the first renovations to the Process Waste Treatment Facility (Building 774) were completed.
- By the end of 1972, plutonium levels in effluents from Building 995 were higher than in the influent; seemed to be related to (1) Building 990 pre-aeration plant had been closed since September 4, 1972 for construction work. In the absence of Building 990, surges of high liquid effluent volume to Building 995 were overloading the system. (2) Supernate, high in radioactivity, had been pumped from the digester to the primary clarifier instead of to the sludge drying beds.

Table A-8. Reported Releases of Gross Alpha and Plutonium from B ponds to South Walnut Creek[a]

Month[b]	Gross alpha (mCi)	Plutonium (mCi)	Ratio[c] (Pu/alpha)	Month[b]	Gross alpha (mCi)	Plutonium (mCi)	Ratio[c] (Pu/alpha)
Jan-70	0.36	0.10	0.26	Apr-72	0.83	0.32	0.38
Feb-70	0.23	0.07	0.31	May-72	0.49	0.13	0.27
Mar-70	0.24	0.09	0.38	Jun-72	0.42	0.15	0.34
Apr-70	0.24	0.12	0.50	Jul-72	0.23	0.08	0.36
May-70	0.44	0.12	0.26	Aug-72	0.13	0.08	0.56
Jun-70	0.10	0.04	0.38	Sep-72	0.30	0.16	0.52
Jul-70	0.37	0.03	0.08	Oct-72	0.54	0.27	0.49
Aug-70	0.07	0.01	0.17	Nov-72	1.97	1.57	0.79
Sep-70	0.12	0.01	0.12	Dec-72	1.86	1.62	0.87
Oct-70	0.40	0.05	0.13	Jan-73	1.06	0.70	0.66
Nov-70	0.74	0.22	0.29	Feb-73	1.45	0.80	0.55
Dec-70	0.40	0.06	0.14	Mar-73	0.74	0.36	0.49
Jan-71	0.26	0.08	0.32	Apr-73	0.85	0.32	0.38
Feb-71	0.95	0.10	0.11	May-73	2.64	0.45	0.17
Mar-71	0.65	0.14	0.22	Jun-73	1.29	0.59	0.46
Apr-71	0.61	0.12	0.20	Jul-73	0.36	0.34	0.94
May-71	0.41	0.09	0.21	Aug-73	0.12	0.10	0.83
Jun-71	0.23	0.05	0.19	Sep-73	0.15	0.12	0.80
Jul-71	0.15	0.07	0.48	Oct-73	0.11	0.08	0.73
Aug-71	0.35	0.03	0.09	Nov-73	0.07	0.04	0.57
Sep-71	0.24	0.09	0.38	Dec-73	0.15	0.11	0.70
Oct-71	0.24	0.04	0.18				
Nov-71	0.51	0.02	0.05	Average	0.57	0.22	0.37
Dec-71	0.62	0.06	0.10	Stdev	0.55	0.34	0.24
Jan-72	0.35	0.06	0.16	Median	0.39	0.10	0.33
Feb-72	1.31	0.25	0.19	Max	2.64	1.62	0.94
Mar-72	1.07	0.15	0.14	Min	0.07	0.01	0.05

[a] From *Status Report--Waste Management Waste Disposal* monthly reports.
[b] Both gross alpha and plutonium were measured during this three-year period.
[c] The ratio of plutonium to gross alpha forms the basis for estimating plutonium releases for earlier years when only gross alpha was measured.

Table A-9. Monthly Plutonium Release Estimates from Pond B to South Walnut Creek for 1953-1969(mCi) [a]

	Percentile Values				Percentile Values				Percentile Values		
Date	95th	50th	5th	Date	95th	50th	5th	Date	95th	50th	5th
Jul-53	0.22	0.06	0.02	Jul-56	0.16	0.04	0.01	Jul-59	0.11	0.04	0.02
Aug-53	0.23	0.05	0.01	Aug-56	0.09	0.03	0.01	Aug-59	0.28	0.11	0.04
Sep-53	0.23	0.06	0.01	Sep-56	0.06	0.02	0.01	Sep-59	0.12	0.05	0.02
Oct-53	0.19	0.06	0.02	Oct-56	0.04	0.01	0.00	Oct-59	0.44	0.16	0.06
Nov-53	0.21	0.06	0.02	Nov-56	0.05	0.02	0.00	Nov-59	0.33	0.13	0.05
Dec-53	0.20	0.06	0.01	Dec-56	0.06	0.02	0.00	Dec-59	0.48	0.18	0.07
Jan-54	1.30	0.33	0.08	Jan-57	0.07	0.02	0.01	Jan-60	0.19	0.08	0.03
Feb-54	0.55	0.14	0.03	Feb-57	0.08	0.02	0.01	Feb-60	0.46	0.17	0.06
Mar-54	0.32	0.08	0.02	Mar-57	0.12	0.03	0.01	Mar-60	0.56	0.21	0.09
Apr-54	0.98	0.25	0.07	Apr-57	0.33	0.09	0.02	Apr-60	0.72	0.26	0.10
May-54	0.79	0.22	0.05	May-57	0.43	0.13	0.04	May-60	0.82	0.33	0.13
Jun-54	0.16	0.05	0.01	Jun-57	0.26	0.07	0.02	Jun-60	0.52	0.20	0.07
Jul-54	0.10	0.02	0.01	Jul-57	0.16	0.04	0.01	Jul-60	0.11	0.04	0.02
Aug-54	0.17	0.05	0.01	Aug-57	0.06	0.02	0.00	Aug-60	0.14	0.05	0.02
Sep-54	0.15	0.05	0.01	Sep-57	0.06	0.02	0.01	Sep-60	0.17	0.06	0.02
Oct-54	0.24	0.07	0.02	Oct-57	0.12	0.03	0.01	Oct-60	0.27	0.11	0.04
Nov-54	0.18	0.05	0.01	Nov-57	0.05	0.01	0.00	Nov-60	0.34	0.12	0.05
Dec-54	0.18	0.05	0.01	Dec-57	0.11	0.03	0.01	Dec-60	0.16	0.07	0.02
Jan-55	0.18	0.05	0.01	Jan-58	0.13	0.04	0.01	Jan-61	0.42	0.16	0.06
Feb-55	0.22	0.06	0.02	Feb-58	0.12	0.03	0.01	Feb-61	0.36	0.14	0.05
Mar-55	0.37	0.09	0.03	Mar-58	0.24	0.07	0.02	Mar-61	0.47	0.16	0.06
Apr-55	0.24	0.07	0.02	Apr-58	0.35	0.10	0.03	Apr-61	0.39	0.16	0.06
May-55	0.11	0.03	0.01	May-58	0.31	0.09	0.02	May-61	0.52	0.20	0.07
Jun-55	0.14	0.04	0.01	Jun-58	0.16	0.04	0.01	Jun-61	0.26	0.10	0.04
Jul-55	0.21	0.06	0.01	Jul-58	0.14	0.04	0.01	Jul-61	0.22	0.09	0.03
Aug-55	0.17	0.05	0.01	Aug-58	0.12	0.03	0.01	Aug-61	0.37	0.15	0.06
Sep-55	0.15	0.04	0.01	Sep-58	0.31	0.08	0.02	Sep-61	0.49	0.18	0.07
Oct-55	0.15	0.04	0.01	Oct-58	0.20	0.06	0.02	Oct-61	0.44	0.17	0.06
Nov-55	0.20	0.05	0.01	Nov-58	0.17	0.06	0.02	Nov-61	0.47	0.17	0.06
Dec-55	0.18	0.05	0.01	Dec-58	0.20	0.07	0.03	Dec-61	0.58	0.21	0.08
Jan-56	0.19	0.05	0.02	Jan-59	0.43	0.16	0.06	Jan-62	1.22	0.44	0.16
Feb-56	0.18	0.05	0.02	Feb-59	0.26	0.10	0.04	Feb-62	0.79	0.29	0.11
Mar-56	0.12	0.03	0.01	Mar-59	0.17	0.06	0.02	Mar-62	0.50	0.20	0.08
Apr-56	0.14	0.04	0.01	Apr-59	0.45	0.16	0.06	Apr-62	0.50	0.18	0.07
May-56	0.34	0.08	0.02	May-59	0.32	0.12	0.05	May-62	0.41	0.16	0.06
Jun-56	0.11	0.03	0.01	Jun-59	0.25	0.10	0.04	Jun-62	0.38	0.15	0.06

[a] Based on monthly ratios of alpha to plutonium measurements from 1970-1973 that were applied to early gross alpha data; this method allows the estimation of plutonium releases for earlier years when only gross alpha was measured.

Table A-9. Monthly Plutonium Release Estimates from Pond B to South Walnut Creek for 1953–1969(mCi) (continued) [a]

	Percentile Values				Percentile Values				Percentile Values		
Date	95th	50th	5th	Date	95th	50th	5th	Date	95th	50th	5th
Jul-62	0.17	0.06	0.02	Jan-65	0.18	0.07	0.03	Jul-67	0.20	0.08	0.03
Aug-62	0.13	0.05	0.02	Feb-65	0.16	0.06	0.02	Aug-67	0.10	0.04	0.01
Sep-62	0.09	0.03	0.01	Mar-65	0.16	0.06	0.02	Sep-67	0.16	0.06	0.02
Oct-62	0.17	0.06	0.02	Apr-65	0.15	0.06	0.02	Oct-67	0.05	0.02	0.01
Nov-62	0.14	0.05	0.02	May-65	0.09	0.03	0.01	Nov-67	0.11	0.04	0.01
Dec-62	0.14	0.05	0.02	Jun-65	0.16	0.06	0.02	Dec-67	0.19	0.07	0.03
Jan-63	0.22	0.08	0.03	Jul-65	0.16	0.07	0.02	Jan-68	0.37	0.14	0.06
Feb-63	0.16	0.06	0.02	Aug-65	0.17	0.07	0.02	Feb-68	0.34	0.13	0.05
Mar-63	0.19	0.07	0.03	Sep-65	0.11	0.04	0.01	Mar-68	0.33	0.13	0.05
Apr-63	0.15	0.06	0.02	Oct-65	0.17	0.07	0.02	Apr-68	0.35	0.13	0.05
May-63	0.19	0.08	0.03	Nov-65	0.27	0.10	0.04	May-68	0.23	0.09	0.04
Jun-63	0.15	0.06	0.02	Dec-65	0.26	0.10	0.04	Jun-68	0.18	0.08	0.03
Jul-63	0.11	0.04	0.02	Jan-66	0.23	0.10	0.04	Jul-68	0.23	0.09	0.04
Aug-63	0.13	0.05	0.02	Feb-66	0.41	0.16	0.06	Aug-68	0.08	0.03	0.01
Sep-63	0.18	0.07	0.03	Mar-66	0.41	0.16	0.06	Sep-68	0.25	0.09	0.03
Oct-63	0.16	0.06	0.02	Apr-66	0.25	0.10	0.04	Oct-68	0.27	0.10	0.03
Nov-63	0.09	0.03	0.01	May-66	0.18	0.07	0.02	Nov-68	0.25	0.09	0.04
Dec-63	0.21	0.08	0.03	Jun-66	0.37	0.13	0.05	Dec-68	0.24	0.09	0.03
Jan-64	0.17	0.07	0.02	Jul-66	0.26	0.10	0.03	Jan-69	0.32	0.11	0.04
Feb-64	0.19	0.07	0.03	Aug-66	0.24	0.10	0.04	Feb-69	0.31	0.11	0.04
Mar-64	0.24	0.09	0.03	Sep-66	0.24	0.09	0.03	Mar-69	0.25	0.10	0.04
Apr-64	0.34	0.11	0.05	Oct-66	0.25	0.09	0.03	Apr-69	0.31	0.12	0.05
May-64	0.15	0.06	0.02	Nov-66	0.24	0.09	0.03	May-69	0.34	0.13	0.05
Jun-64	0.21	0.08	0.03	Dec-66	0.25	0.09	0.04	Jun-69	0.52	0.20	0.08
Jul-64	0.08	0.03	0.01	Jan-67	0.24	0.10	0.03	Jul-69	0.33	0.12	0.05
Aug-64	0.12	0.04	0.01	Feb-67	0.23	0.09	0.04	Aug-69	0.27	0.11	0.04
Sep-64	0.12	0.05	0.02	Mar-67	0.38	0.14	0.06	Sep-69	0.11	0.04	0.01
Oct-64	0.25	0.10	0.03	Apr-67	0.32	0.12	0.05	Oct-69	0.08	0.03	0.01
Nov-64	0.18	0.07	0.03	May-67	0.36	0.14	0.05	Nov-69	0.07	0.03	0.01
Dec-64	0.16	0.06	0.02	Jun-67	0.23	0.09	0.03	Dec-69	0.16	0.06	0.02

[a] Based on monthly ratios of alpha to plutonium measurements from 1970-1973 that were applied to early gross alpha data; this method allows the estimation of plutonium releases for earlier years when only gross alpha was measured.

Table A-10. Tritium Levels in the Great Western Reservoir[a]

Date	Conc. (pCi L^{-1})	Error[b] (pCi L^{-1})	Date	Conc. (pCi L^{-1})	Error[b] (pCi L^{-1})	Date	Conc. (pCi L^{-1})	Error[b] (pCi L^{-1})
6/25/70	1722	534	5/10/73	3717	516	12/12/73	9256	572
9/17/70	1156	508	5/16/73	3686	514	12/18/73	9541	593
9/17/70	1154	506	5/16/73	4378	525	12/28/73	9248	590
4/13/71	1018	472	5/24/73	3555	518	1/9/74	9646	599
4/13/71	1112	472	5/24/73	3778	517	1/15/94	10234	584
4/13/71	703	467	6/1/73	22844	728	1/21/94	10231	584
10/7/71	-500	MDA	6/1/73	23293	735	1/30/74	9606	577
			6/7/73	18994	690	2/5/74	8881	579
9/12/72	1206	489	6/7/73	18394	686	2/13/74	9499	570
9/20/72	1497	493	6/15/73	19439	697	2/21/74	8721	561
9/30/72	959	477	6/21/73	16019	662	2/16/74	9034	580
10/6/72	1085	479	6/27/73	16934	672	4/3/74	8726	570
10/14/72	773	474	7/3/73	15809	660	4/5/74	8167	567
10/20/72	1182	478	7/11/73	14625	647	4/8/74	8277	558
10/26/72	500	MDA	7/19/73	12520	627	5/8/74	7371	556
11/4/72	706	471	7/25/73	12429	666	5/14/74	6457	545
11/14/72	838	473	8/2/73	13286	635	5/20/74	6434	550
11/22/72	1150	478	8/8/73	13139	922	5/28/74	5284	512
11/28/72	1303	480	8/14/73	12354	912	7/1/74	4290	510
			8/24/73	10847	893	7/10/74	3846	493
1/4/73	500	MDA	8/31/73	12525	914	7/16/74	3590	490
1/10/73	703	501	9/7/73	11222	898	7/22/74	3574	490
1/20/73	1884	525	9/13/73	10558	980	7/30/74	2948	603
1/26/73	684	526	8/8/73	10795	723	8/7/74	3091	605
2/1/73	1082	562	8/14/73	11144	727	8/12/74	2795	602
2/9/73	769	558	8/24/73	10232	576	8/21/74	3059	572
2/15/73	908	560	8/28/73	10162	575	8/26/74	2858	570
2/23/73	753	558	9/7/73	10350	577	9/9/74	3079	573
3/1/73	737	557	9/20/73	9918	572	9/16/74	3193	508
3/9/73	643	556	9/27/73	6865	536	9/24/74	3263	487
3/15/73	978	561	10/3/73	9774	571	10/3/74	3572	492
3/25/73	500	MDA	10/11/73	9806	571	10/7/74	3007	483
3/29/73	683	478	10/17/73	10373	577	10/16/74	3064	484
4/4/73	514	417	10/23/73	9976	482	10/21/74	3037	483
4/12/73	854	472	10/25/73	10272	566	10/30/74	3677	500
4/18/73	1462	481	10/31/73	10317	573	11/4/74	3345	496
4/26/73	2694	519	11/8/73	10144	571	11/11/74	3109	507
4/26/73	3531	518	11/12/73	10183	571	11/18/74	3609	516
5/4/73	4030	518	11/20/73	9279	567	11/25/74	3553	515
5/4/73	4786	530	11/26/73	9269	567	12/2/74	3469	504
5/10/73	3496	511	12/4/73	9893	580	12/9/74	3282	501

Table A-10. Tritium Levels in the Great Western Reservoir (continued) [a]

Date	Conc. (pCi L^{-1})	Error[b] (pCi L^{-1})	Date	Conc. (pCi L^{-1})	Error[b] (pCi L^{-1})	Date	Conc. (pCi L^{-1})	Error[b] (pCi L^{-1})
12/16/74	3337	485	9/15/75	892	474	6/28/76	978	467
12/23/74	3136	482	9/22/75	1288	480	7/6/76	760	455
1/3/75	3406	486	9/29/75	554	469	7/12/76	571	452
1/13/75	3598	489	10/6/75	796	454	7/19/76	893	457
1/20/75	2867	580	10/13/75	885	455	7/26/76	500	MDA
1/27/75	2699	577	10/20/75	1160	448	8/16/76	500	MDA
2/3/75	3224	584	10/31/75	1213	449	8/23/76	563	449
2/10/75	3419	500	11/3/75	788	443	8/30/76	1172	454
2/19/75	3038	495	11/10/75	667	458	9/8/76	500	MDA
2/26/75	3069	469	11/17/75	1176	466	9/13/76	500	MDA
3/3/75	2691	494	11/24/75	899	462	9/20/76	588	463
3/10/75	2890	496	12/1/75	910	462	9/27/76	1184	472
3/17/75	3269	502	12/8/75	1088	459	10/4/76	716	462
3/24/75	2982	498	12/15/75	812	453	10/13/76	500	MDA
4/14/75	3026	501	12/22/75	1006	455	10/18/76	1414	473
4/21/75	2816	494	12/29/75	1072	456	10/27/76	586	450
4/28/75	2321	487	2/2/76	766	465	11/1/76	500	MDA
5/5/75	3239	506	2/9/76	1038	475	11/8/76	660	464
5/12/75	3441	492	2/18/75	704	470	11/15/76	642	452
5/19/75	2828	483	2/23/76	656	469	11/22/76	991	458
5/27/75	2972	485	4/6/76	583	470	11/29/76	1092	474
7/7/75	1677	455	4/12/76	1366	481	12/6/76	500	MDA
7/14/75	1058	469	4/19/76	857	474	12/13/76	804	475
7/21/75	1421	475	4/26/76	970	476	12/20/76	500	MDA
7/28/75	1024	487	5/3/76	1254	479	12/27/76	500	MDA
8/6/75	988	449	5/10/76	747	493	1/3/77	500	MDA
8/11/75	735	455	5/17/76	758	493	1/12/77	500	MDA
8/18/75	1065	460	5/24/76	1488	503	1/17/77	500	MDA
8/28/75	1006	471	6/7/76	1178	468	1/24/77	500	MDA
9/1/75	718	472	6/14/76	853	471	1/31/77	500	MDA
9/8/75	822	474	6/21/76	1007	468	2/7/77	1143	460

[a] From CDH (1970–1978); MDA = less than the minimum detectable activity.

[b] Error term is the 2 sigma counting error for the single determination.

APPENDIX B

BACKGROUND LEVELS OF PLUTONIUM IN SURFACE WATER

GENERAL PERSPECTIVE ON PLUTONIUM CONCENTRATIONS IN WATER

Information about levels of plutonium in water from sources other than Rocky Flats provides perspective for surface water measurements at the RFP. Four major mechanisms that are important to the movement of radionuclides in surface water are deposition from the atmosphere, runoff and soil erosion from land surfaces, movement of the surface water, and transfer between sediments and water (Jirka et al. 1983). Plutonium occurs in the environment primarily due to fallout from atmospheric nuclear weapons tests. In the early years of operations at the RFP (the 1950s and 1960s, at least), there were significant temporal trends in quantities of plutonium fallout from weapons tests (Rope et al. 1999). Because of the dynamic processes in the transport and dilution of radionuclides in surface waters, significant temporal trends in the concentrations of plutonium in surface water would also be expected.

A report prepared for the Agency for Toxic Substances and Disease Registry provides general information about plutonium in the environment (Clement 1990). This appendix compiles measured concentrations of plutonium in various sources of water (Table B-1). These values are intended to provide general perspective on levels of plutonium in various background and contaminated waters, especially during the time of higher releases from the RFP.

Table B-1. Plutonium Concentrations Measured in Various Waters[a]

Location (Pu Isotopes)	Range of plutonium concentrations		Comments
	Bq L^{-1}	fCi L^{-1}	
North Pacific surface water (^{238}Pu + $^{239,240}Pu$)	8.2×10^{-6}– 3.5×10^{-5}	0.22–0.94	
South Pacific surface water (^{238}Pu + $^{239,240}Pu$)	4.8×10^{-6}– 1.3×10^{-5}	0.13–0.34	
South Carolina: estuary waters ($^{239,240}Pu$)	6.3×10^{-6}– 9.4×10^{-5}	0.17–2.5	Received effluent from Savannah River Plant
South Carolina: river waters ($^{239,240}Pu$)	1.6×10^{-5}– 8.3×10^{-5}	0.43–2.3	Received effluent from Savannah River Plant
New York City: drinking water ($^{239,240}Pu$)	3.0×10^{-6}– 2.3×10^{-5}	0.08–0.61	
Enewetak, South Pacific: groundwater ($^{239,240}Pu$)	7.4×10^{-6}– 1.0×10^{-2}	0.20–280	Some weapons tests were at Enewetak
Idaho National Engineering Laboratory: groundwater (^{238}Pu)	4.1×10^{-4}– 2.9×10^{-3}	11–78	Near a disposal well
Nevada Test Site: groundwater (^{239}Pu)	1.6×10^{-3}– 9.6×10^{-2}	42–2600	Underground nuclear weapons tests at site

[a] Measurements in this table were compiled by Clement (1990) from other original sources.

From these locations, plutonium concentrations in water contaminated by local nuclear weapons testing or releases from weapons production sites range widely, from 6.3×10^{-6} to 9.6×10^{-2} Bq L^{-1} (0.17 to 2600 fCi L^{-1}). Concentrations in waters not contaminated by such local sources cover a smaller range, from 3.0×10^{-6} to 3.5×10^{-5} Bq L^{-1} (0.08 to 0.94 fCi L^{-1}). It is noted that these measurements are only a small data set.

REGIONAL BACKGROUND PLUTONIUM CONCENTRATIONS IN WATER

There are some data on concentrations of plutonium in waters in the general region of the RFP. A small number of measurements were made in 1969 (after the May 1969 fire) by Poet and Martell (1972) in lakes near the RFP that did not receive liquid effluents from the RFP (Table B-2). These included Boyd Lake near Loveland, and Boulder Reservoir and Dodd's Lake, northeast of Boulder. Results were given in units of dpm L^{-1}, but have been converted to Bq L^{-1} and fCi L^{-1} in Table B-2.

Table B-2. Concentrations of ^{239,240}Pu Measured in 1969 in Lakes Unaffected by Liquid Effluents from the Rocky Flats Plant [a]

Location	Collection date	Bq L^{-1}	fCi L^{-1}
Boulder Reservoir, NE of Boulder	9/11/69	$2.7 \times 10^{-4} \pm 2.7 \times 10^{-4}$	7.2 ± 7.2
Dodd's Lake, NE of Boulder	8/31/69	$3.8 \times 10^{-4} \pm 6.7 \times 10^{-5}$	10 ± 1.8
Dodd's Lake, NE of Boulder	9/11/69	$4.8 \times 10^{-4} \pm 2.3 \times 10^{-4}$	13 ± 6.3
Boyd Lake, Loveland	9/22/69	$5 \times 10^{-5} \pm 3 \times 10^{-5}$	1.4 ± 0.9

[a] The "±" values are one standard deviation analytical errors (Poet and Martell 1972).

In Phase I of this Historical Public Exposures Studies, ChemRisk compiled data on radionuclide concentrations in reservoirs and drinking water in the area of the RFP (ChemRisk 1992). Of the data examined by ChemRisk, the only measurements with plutonium-specific analyses were performed for years 1970 and later. For earlier years, only gross alpha analyses were available. ChemRisk obtained data for 1970–1988, taken by the CDH, for drinking water of three towns that used reservoirs a considerable distance from the RFP that did not receive runoff or liquid effluents from the RFP. The data were obtained from Monthly Environmental Surveillance Reports of the CDH, and annual averages were calculated by ChemRisk. Table B-3 shows the calculated annual average concentrations of ^{239,240}Pu. Of the 147 individual measurements used to calculate the annual averages, only 24 were "detected" concentrations. The rest were reported as "less than" values. To calculate the annual average concentrations, ChemRisk replaced the less than values with one-half the detection limit, and then performed the average. This method was thought to produce averages that were higher than the actual annual average concentrations (ChemRisk 1992).

Table B-3. Annual Average Concentrations of $^{239,240}Pu$ in Drinking Waters Not Affected by Liquid Effluents from the Rocky Flats Plant[a]

	pCi L^{-1}			Bq L^{-1}		
Year	Arvada	Boulder	Golden	Arvada	Boulder	Golden
1970	0.015	[b]	0.02	5.6×10^{-4}	[b]	7.4×10^{-4}
1971	0.01	[b]	[b]	3.7×10^{-4}	[b]	[b]
1972	0.01	0.025	0.027	3.7×10^{-4}	9.2×10^{-4}	1.0×10^{-3}
1973	0.013	0.01	0.013	4.8×10^{-4}	3.7×10^{-4}	4.8×10^{-4}
1974	0.01	0.01	0.01	3.7×10^{-4}	3.7×10^{-4}	3.7×10^{-4}
1975	0.43	0.245	0.045	1.6×10^{-2}	9.1×10^{-3}	1.7×10^{-3}
1976	[b]	[b]	[b]	[b]	[b]	[b]
1977	[b]	[b]	[b]	[b]	[b]	[b]
1978	0.03	0.01	0.03	1.1×10^{-3}	3.7×10^{-4}	1.1×10^{-3}
1979	0.01	[b]	0.01	3.7×10^{-4}	[b]	3.7×10^{-4}
1980	0.01	0.01	0.01	3.7×10^{-4}	3.7×10^{-4}	3.7×10^{-4}
1981	0.01	0.01	0.011	3.7×10^{-4}	3.7×10^{-4}	4.1×10^{-4}
1982	0.01	0.0175	0.015	3.7×10^{-4}	6.5×10^{-4}	5.6×10^{-4}
1983	0.0275	0.041	0.01	1.0×10^{-3}	1.5×10^{-3}	3.7×10^{-4}
1984	0.46	0.256	0.0275	1.7×10^{-2}	9.5×10^{-3}	1.0×10^{-3}
1985	0.35	0.03	0.02	1.3×10^{-2}	1.1×10^{-3}	7.4×10^{-4}
1986	0.0075	0.014	0.005	2.8×10^{-4}	5.2×10^{-4}	1.8×10^{-4}
1987	0.004	0.004	0.004	1.5×10^{-4}	1.5×10^{-4}	1.5×10^{-4}
1988	0.002	0.0013	0.003	7.4×10^{-5}	4.8×10^{-5}	1.1×10^{-4}

[a] Averages were calculated by ChemRisk (1992) from CDH data. ChemRisk said the averages are biased high, due to the way the nondetect results were handled (see text).

[b] No samples obtained for this year.

Routine monitoring of radioactivity in various environmental media at many locations in the U.S. is currently performed by the National Air and Radiation Environmental Laboratory (NAREL) of the EPA. The present routine monitoring was started by the U.S. Public Health Service (PHS) over 35 years ago. The two agencies issued routine reports with titles that changed with time, as given in Table B-4. For the period 1981–1990, surface water samples were not analyzed for plutonium or for gross alpha radioactivity. The most relevant data for this period are measurements of gross alpha radioactivity and plutonium in drinking water for Denver and Platteville, Colorado.

Table B-4. Routine Monitoring Reports by the Public Health Service (PHS) and the U.S. Environmental Protection Agency (EPA)

Years	Agency	Report titles[a]
1960–1970	PHS	Radiological Health Data
1971	EPA	Radiological Health Data and Reports
1972–1975	EPA	Radiation Data and Reports
1975–1994	EPA	Environmental Radiation Data

[a] There were slight variations in titles.

The EPA measurements of gross alpha radioactivity and plutonium in drinking water and plutonium in rainwater are shown in Table B-5 (EPA 1981, 1982a, 1982b, 1983, 1984a, 1984b, 1985a, 1985b, 1985c, 1985d, 1987a, 1987b, 1988a, 1988b, 1989a, 1989b, 1990, 1993a, 1993b, 1993c, and 1994). These data are results of analyses of annual composite samples, and so represent an annual average value. The EPA reports included analytical uncertainties of the measurements. For the plutonium measurements, in most cases the analytical uncertainties (given as 2 σ errors) were about equal to the results; the uncertainty in the plutonium values are very great. The detection limit was indicated to be 0.015 pCi per sample for plutonium, but it is not clear in all cases the volume of each sample. From the uncertainties given, it appears that most of the plutonium results are very near the detection limit. Negative results are presumed due to gross analysis results less than the analysis background for the method and instruments used.

Table B-5. Annual Average Concentrations of Gross Alpha Radioactivity and Plutonium in Colorado Drinking Water (pCi L^{-1}) [a]

	Gross alpha		^{238}Pu		^{239,240}Pu	
Year	Denver	Platteville	Denver	Platteville	Denver	Platteville
1980	4.0	4.0	0.008	[b]	[b]	[b]
1981	3.7	4.9	−0.004	0.042	0.006	0.005
1982	2.7	10.1	0.009	0.000	[b]	−0.002
1983	2.0	12.0	0.017	0.006	0.003	0.002
1984	2.7	18.2	0.008	0.038	0.002	0.012
1985	1.1	21.4	[b]	0.738	[b]	0.081
1986	1.1	19.0	[b]	0.011	[b]	0.002
1987	−0.1	9.3	[b]	0.007	[b]	−0.002
1988	1.0	11.6	0.005	0.001	0.004	0.003
1989	2.6	13.4	[d]	0.002	[c]	[c]
1990	0.7	7.1	[b]	[b]	[b]	[b]
1991	1.2	9.2	[b]	[c]	[b]	0.003
1992	1.8	14.3	0.008	0.022	0.001	0.005

[a] Results of analyses of annual composite samples by the EPA. For the last two columns of data here, results were reported as ^{239}Pu, but we assume they are actually ^{239,240}Pu.
[b] No sample was obtained.
[c] Sample analysis result was “not detected.”

The data (Table B-5) indicate that the concentrations of plutonium in drinking water were generally less than 1% of the gross alpha radioactivity. This is expected, as the background quantities in the environment of naturally occurring uranium, thorium, and radium, which are all alpha-emitters, are significantly higher than background quantities of plutonium in the environment.

For the drinking water analyses, there were no significant trends in the data, other than the very high results for plutonium in Platteville drinking water obtained in 1985. The reason for the abnormally high value is not known. For years other than 1985, the concentrations of ^{238}Pu in drinking water of Denver and Platteville ranged from negative values to 0.042 pCi L^{-1} (0.0016

Bq L^{-1}), and the concentrations of $^{239,240}Pu$ ranged from negative values to 0.012 pCi L^{-1} (0.00044 Bq L^{-1}).

These data on concentrations of plutonium in surface water and drinking water are helpful for general perspective on other measurements of plutonium in water made around the RFP. Of these, however, only a small number are plutonium-specific measurements for background surface water in the general area of the RFP.

REFERENCES FOR APPENDIX B

Clement (Clement International Corporation). 1990. *Toxicological Profile for Plutonium*. Report TP-90-21, prepared for the Agency for Toxic Substances and Disease Registry, Public Health Service, U.S. Department of Health and Human Services.

EPA (U.S. Environmental Protection Agency). 1981. *Environmental Radiation Data, Report 25 – 26*. Office of Radiation Program, EPA.

EPA. 1982a. *Environmental Radiation Data, Report 29 (January - March 1982)*. Report EPA 520/5-5-83-005, Office of Radiation Programs, EPA, Washington, D.C.

EPA. 1982b. *Environmental Radiation Data, Report 30 (April - June 1982)*. Report EPA 520/5-6-83-006, Office of Radiation Programs, EPA, Washington, D.C.

EPA. 1983. *Environmental Radiation Data, Report 33 (January - March 1983)*. Report EPA 520/5-83-016, Office of Radiation Programs, EPA, Washington, D.C.

EPA. 1984a. *Environmental Radiation Data, Report 36 (October - December 1983)*. Report EPA 520/5-84-013, Eastern Environmental Radiation Facility, EPA, Montgomery, Alabama.

EPA. 1984b. *Environmental Radiation Data, Report 39 (July - September 1984)*. Report EPA 520/5-85-009, Eastern Environmental Radiation Facility, EPA, Montgomery, Alabama.

EPA. 1985a. *Environmental Radiation Data, Report 40 (October - December 1984)*. Report EPA 520/5-85-022, Eastern Environmental Radiation Facility, EPA, Montgomery, Alabama.

EPA. 1985b. *Environmental Radiation Data, Report 41 (January - March 1985)*. Report EPA 520/5-85-030, Eastern Environmental Radiation Facility, EPA, Montgomery, Alabama.

EPA. 1985c. *Environmental Radiation Data, Report 42 (April - June 1985)*. Report EPA 520/5-85-031, Eastern Environmental Radiation Facility, EPA, Montgomery, Alabama.

EPA. 1985d. *Environmental Radiation Data, Report 43 (July - September 1985)*. Report EPA 520/5-86-007, Eastern Environmental Radiation Facility, EPA, Montgomery, Alabama.

EPA. 1987a. *Environmental Radiation Data, Report 47*. Report EPA 520/5-87-006, Eastern Environmental Radiation Facility, Office of Radiation Programs, EPA, Montgomery, Alabama.

EPA. 1987b. *Environmental Radiation Data, Report 48, October 1986 - December 1986*. Report EPA 520/5-87-017, Eastern Environmental Radiation Facility, EPA, Montgomery, Alabama.

EPA. 1988a. *Environmental Radiation Data, Report 51, July 1987 - September 1987*. Report EPA 520/5-88-013, Eastern Environmental Radiation Facility, EPA, Montgomery, Alabama.

EPA. 1988b. *Environmental Radiation Data, Report 54, April - June 1988*. Report EPA 520/5-88-058, Eastern Environmental Radiation Facility, Office of Radiation Programs, EPA, Montgomery, Alabama.

EPA. 1989a. *Environmental Radiation Data, Report 55, July - September 1988*. Report EPA 520/5-89-011, Eastern Environmental Radiation Facility, Office of Radiation Programs, EPA, Montgomery, Alabama.

EPA. 1989b. *Environmental Radiation Data, Report 57, January - March 1989*. Report EPA 520/5-89-021, Eastern Environmental Radiation Facility, Office of Radiation Programs, EPA, Montgomery, Alabama.

EPA. 1990. *Environmental Radiation Data, Report 59, July - September 1989*. Report EPA 520/5-90-003, Eastern Environmental Radiation Facility, Office of Radiation Programs, EPA, Montgomery, Alabama.

EPA. 1993a. *Environmental Radiation Data, Report 67, July-September 1991*. Report EPA-400-R-93-019, National Air and Radiation Environmental Laboratory, Office of Radiation Programs, EPA, Montgomery, Alabama.

EPA. 1993b. *Environmental Radiation Data, Report 70, April-June 1992*. Report EPA-402-R-93-089, National Air and Radiation Environmental Laboratory, Office of Radiation and Indoor Air, EPA, Montgomery, Alabama.

EPA. 1993c. *Environmental Radiation Data, Report 72, October-December 1992*. Report EPA-402-R-93-091, National Air and Radiation Environmental Laboratory, EPA, Montgomery, Alabama.

EPA. 1994. *Environmental Radiation Data, Report 74, April-June 1993*. Report EPA-402-R-93-093, National Air and Radiation Environmental Laboratory, Office of Radiation and Indoor Air, EPA, Montgomery, Alabama.

Jirka G.H., A.N. Findikakis, Y. Onishi, and P.J. Ryan. 1983. "Transport of Radionuclides in Surface Waters." In: Till J.E. and H.R. Meyer, eds. *Radiological Assessment: A Textbook on Environmental Dose Analysis*. Report NUREG/CR-3332, ORNL-5968, U.S. Nuclear Regulatory Commission, Washington, D.C.

Poet S.E. and E.A. Martell. 1972. "Plutonium-239 and Americium-241 Contamination in the Denver Area." *Health Physics* 23:537–548.